RELATIONSHIP BETWEEN PERCEPTUAL RATINGS OF NASALITY DURING CUL-DE-SAC TESTING AND NASALANCE SCORES

BY

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To Dr. Kenneth R. Bzoch

for the much he has taught us,

and

to the Patients of Centrinho

for the much they allowed me to learn...

ACKNOWLEDGMENTS

Take pride, take time, take care, give love, be yourself! God never makes mistakes... (Richardo Keens-Douglas)

A seed was planted, some time ago, at the Hospital for Research and Rehabilitation of Cleft Palate Lesions, Bauru, Brazil. Rosana Buchala and Cristina Zimmermann first nurtured it, with the wisdom of many years of experience. Dr. Maria Inês Pegoraro-Krook added fertilizer, and realized that new soil was needed for the plant to fully grow. Dr. José Alberto de Souza Freitas supported the "growing project", and the Government of Brazil/CNPq picked-up the costs from there.

The seedling was sent to the University of Florida. At the Department of Communication Processes and Disorders new soil was added to the pot, while plenty of water came from the UF Craniofacial Center. Under the mentoring hands of Dr. Bill Williams development took place, with Drs. Ken Bzoch, Sam Brown, Chris Sapienza, Howard Rothman, Maria Inês Pegoraro-Krook and Steve Boggs carefully monitoring its curse.

Along the way there were times too cold or too dry for anything to grow. The warmth of Izabel and Olivia and the fighting spirit that own to my Mother, Donata, helped the plant to thrive and blossom.

If God allows me to "live" the lessons that I have learned and to apply the knowledge which I have gained, many more blossoms are sure to come. For all of those who took pride, took time, took care, gave love, and were their best while guiding me, I own more than thankful words. Shall the product of my work stand for itself and tell what words can't say...

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RELATIONSHIP BETWEEN PERCEPTUAL RATINGS OF NASALITY DURING CUL-DE-SAC TESTING AND NASALANCE SCORES

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The relationship between auditory-listener perceptual ratings of hypernasality and instrumental measures of nasalance were investigated in this study. Twenty listeners rated cul-de-sac pairs recorded from 40 subjects during production of the single word "bebê" and the short phrase "o bebê babou". Resonance shift during cul-de-sac testing, therefore, provided the perceptual indicator of presence of hypernasality, while nasalance scores, simultaneously obtained with the Nasometer, provided the instrumental measure indicating the ratio of oral to nasal acoustic energy. Correlation and estimation analysis revealed levels of agreement between the perceptual and instrumental measures for a) all subjects, b) subjects who received perceptual ratings indicating 70% or more listener agreement, and c) subjects who received perceptual ratings indicating 85% or more listener agreement. Correlation coefficients and

estimation measures of Nasometer sensitivity and specificity in confirming the presence or absence of hypernasality, increased as level of agreement between judges increased. The finding of this study suggest that the usefulness of the Nasometer in correctly predicting presence or absence of hypernasality is closely related to listener agreement and the consistency with which the perceptual tool providing the standard measure is used.

CHAPTER 1
INTRODUCTION AND REVIEW OF TERMS

The habilitation community involved in assessment and treatment of communicative disorders continues to try to construct valid and reliable rating scales for quantifying the severity of voice, articulation, and resonance disorders. Judging the "goodness" or "badness" of a speaker's speech quality appears to be as elusive and variant as the task of judging the attractiveness or unattractiveness of a person's face. People of most societies usually agree when all the morphologic components of a particular face result in extreme attractiveness or beauty, or conversely when the face is atypically or abnormally configured as to result in extreme unattractiveness. It is the huge expanse of "middle ground" (the nearly infinite variations in facial features between the beautiful face and the unattractive face), however, that results in conflicting opinion as to the degree of attractiveness/unattractiveness that a particular face possesses.

Similar to our ability (or lack of) in judging facial attractiveness, most people in any society usually agree when an individual's speech sounds extremely good or pleasant, or when an individual's speech, even if intelligible, sounds unacceptably unpleasant to listen to. Here too, it is the

large range between the extremely good speech quality and the unpleasant--unacceptable quality that results in conflicting opinion as to the absolute degree of "goodness" or unacceptability. From a clinical perspective, therefore, the selection of treatment options and the verification of treatment outcomes seems to depend on the development of stable and predictable tools for assessing communication behaviors.

This study addresses both perceptual and instrumental assessment of speech and focuses on defining the relationship between a perceptual and an instrumental measure of speech nasality. A review of nasality, therefore, as an aspect of speech resonance follows.

Speech Resonance

Speech resonance, in general, still is not a completely understood phenomena (McWilliams, Morris, & Shelton, 1990). The term resonance per se carries popular, musical and scientific meanings. As an aspect of speech production, resonance refers to the physics of vibration of the molecules of air (e.g. amplification, dampening) as they travel through the vocal tract (Daniloff, Schuckers, & Feth 1980).

Even though the laryngeal as well as the infra-laryngeal structures and passageways have a role as resonators, usually only the supra-laryngeal cavities and structures are designated as the resonators for sound energy. Witzel (1995), however, cites all the following structures and

spaces as possible resonators during speech production: trachea, bronchial tube, lungs, rib cage, laryngeal ventricle, epiglottis, thyroid cartilage, aryepiglottic folds, pharynx, tongue, oral cavity, facial muscles, cheek muscles, mastication muscles, soft and hard palates, nasal cavity, and paranasal sinuses. Witzel continues her discussion stating that:

> a sound wave is produced when a mechanical disturbance, such as the vibration of vocal cords, creates a high-pressure area that moves through air . . . {as} this high-pressure area passes through an enclosed space, the waves are repeated and amplified, and a resonating cavity is created. The volume of the cavity determines the number of simultaneous sound waves. All surfaces have a natural frequency at which they begin to vibrate. If the frequency in a cavity surface is the same as that of the sound wave, the surface also vibrates, sending separate sound waves . . . Each type of speech sound, which is characterized according to the manner and place of production, involves different resonating cavities and structures. (page 145)

In agreement with Witzel's statement, Daniloff and colleagues (1980) explained that the energy-conducting efficiency of a resonating system depends upon the frequency selective filtering conditions of the acoustic tube receiving the column of air set into vibration. Sound filtering, therefore, varies according to size, shape, and surface of the resonating structures and cavities.

In attempts to understand and explain how air molecules are further modified after leaving the laryngeal space, text books usually "dissect" speech resonance from other aspects of speech production. The overall process of speech production, however, is very dynamic and even though a phenomenon (e.g. speech resonance) or a feature (e.g.

nasality) can be described as an isolated entity for teaching purposes, these are only parts of integrated processes involving interactions between four complex systems: respiratory, laryngeal, articulatory and nervous.

The generation of the driving forces for speech initiates at the respiratory level with air naturally flowing from a region of higher pressure to one of lower pressure. Regulation and control of speech aerodynamics at the lower airway, as Lass described, involves

> a complex interplay between muscular and non-muscular forces {resulting in the generation of a} . . . constant pressure head {necessary to} . . . power speech. As lung volume decreases . . . pressure is maintained by the respiratory muscles, which check elastic recoil and prevent over-pressure or compress the chest cage further to prevent under pressure as speech is produced. (page 51, 1996)

As air continues traveling up through the vocal tract it can be modified by a series of five valves, according to Witzel (1995): 1) laryngeal, 2) velopharyngeal (VP), 3) nasal, 4) tongue with hard palate, soft palate, or teeth, and 5) lips together or with teeth. The structures within the vocal tract, therefore, play an essential role in modulating/filtering the air-stream into precise patterns of sounds, each carrying distinctive physiological features according to manner, place, voicing, and nasality of production. Both direction and resistance to airflow are important factors in the definition of these distinctive features.

Direction of airflow is particularly important for the distinction of nasality features of speech. While most

speech is directed through the oral air-tract, production of nasal vowels requires directing air through oral and nasal tracts, and through the nasal tract alone during production of nasal consonants (Lass, 1996). Opening of the VP valve generates the vocal tract configuration necessary for production of nasal sounds. Therefore, for nasalization to occur, as Lass (1996) has described, "the long acoustic tube formed by the combined pharyngeal and nasal cavities is coupled to the shorter tube formed by the oral cavity (a side-branch resonator), which is open at both ends for nasal vowels and open only at one end for nasal consonants" (page 196). Nasality, therefore, emerges here as the speech feature associated with an interaction between nasal, oral, and pharyngeal cavities. During such an interaction, reduced impedance is offered to the sound energy entering the nasal airway through an open VP valve. As Lass (1996) described:

> the nasal cavities affect the acoustic output not only through the length of the tube but through the shape and tissue quality of the passages. Specifically, the soft and convoluted mucous membranes of the nasal cavity absorb sound. The general result of these interactions is a reduction in the overall energy of the vowel and a widening of the formant bandwidths. In the case of nasal consonants, closure of the oral tract contributes distinctive antiformants as the oral cavity short-circuits sound energy from the larynx, preventing its radiation through the nasal passages . . . in addition to introducing antiformants, the coupling of the nasal passages to the vocal tract increases the overall length of the tract, lowering formant frequencies generally and creating a distinctive low . . . resonance called nasal murmur or nasal formant. (pages 196 and 197)

Nasality, as described here, is a natural feature of many languages and can be normally present during production of both vowels or consonants. As Fletcher, Adams and

McCutcheon (1989) reported "nasal consonants are found in virtually every language of the world and nasalized vowels in about one out of five... {reflecting} the fact that nasal resonance is a highly distinctive, readily perceived acoustic quality which may be mixed with orally produced sounds to invoke specific phonetic contrasts" (page 246).

While the nasal sounds of the English language include only the consonants /m/ as in "my", /n/ as in "no", and /ŋ/ as in "sing", sound segments (e.g. vowels) that occur in combination with these nasal consonants can also become nasalized (Daniloff et al., 1980). Nasal sounds for languages other than English vary according to each language. In Brazilian Portuguese, for instance, nasal sounds include the consonants /m/ as in "mesa", /n/ as in "nada", /ñ/ as in "ninho", plus several nasal vowels such as /~i/ as in "sim" and "incerto", /~e/ as in "ensino", /~ə/ as in "amanhã", /~u/ as in "untar" and "pão", and /õ/ as in "onça" (Mascherpe, 1970).

The term nasality, therefore, is used in this chapter in reference to the speech feature necessary for the perception of all nasal sounds. Nasalization, on the other hand, is used in reference to the physiological event of coupling the nasal cavity as an additional resonance chamber during production of nasal sounds and neighboring sound segments. Conditions in which nasalization either is reduced during production of nasal sounds or is perceived during production of oral sounds for which anticipatory or carryover

nasalization is not expected, will be described next as sub-categories of resonance disorders.

Resonance Disorders

In the field of speech pathology the term resonance disorder has been most often associated with speech conditions involving some degree of oral-nasal coupling dysfunction. The uniqueness of each individuals' vocal quality, however, as related to different aspects of the resonance-articulation phenomena, lies beyond a certain degree of oral-nasal coupling and includes further variations of resonance patterns. Witzel (1995) for example, describes several types of abnormal vocal resonance problems using the following terms: hyponasal resonance, denasal resonance, cul-de-sac resonance, muffled resonance, and hypernasal resonance. D'Antonio and Scherer (1995) have added mixed resonance or hyper-hyponasal resonance pattern to this list of vocal resonance problems.

According to Witzel's definition, hyponasal, denasal, and cul-de-sac resonance are variations of conditions in which the coupling of the nasal cavity as a resonance chamber is compromised. The nasal cavity, as Witzel (1995) has described, can be partially or completely blocked, and it can be blocked anteriorly (e.g. deviated nasal septum) or posteriorly (e.g. enlarged adenoid). Witzel continues describing hyponasal resonance as the pattern of speech that results "when a partial blockage in the nose increases the

airflow resistance, thereby reducing the sound wave vibration in the nasal cavity and altering the acoustic production of the nasal consonants /m/, /n/, and /ŋ/" (page 145). Witzel describes denasal resonance as the pattern of speech produced "when the nose is completely blocked, preventing almost all vibration of sound waves {with} in the nasal cavity . . . {a} situation {in which} the nasal consonants approximate the oral consonants /b/, /d/, and /g/" (page 145). She then refers to the condition of cul-de-sac resonance as a variation of hyponasality and denasality, involving an anterior rather than a posterior nasal obstruction.

Witzel (1995) further differentiates hyponasal, denasal, and cul-de-sac resonance from another abnormal resonance condition called muffled resonance which she defines as the pattern of speech associated with the presence of reduced naso- and oropharyngeal space, a condition which could involve retro-positioning of the tongue as well as bony deformities of the facial skeleton.

All of these conditions can yet be differentiated from the abnormal condition of hypernasal resonance which Witzel defined as the pattern of speech that "occurs when the sound waves emanating from the vocal folds enter both the oral and nasal cavities during speech, causing both cavity chambers to vibrate and enhance the sound waves" (page 145). Finally, a hyper-hyponasal resonance pattern also has been described by D'Antonio and Scherer (1995) as the "simultaneous occurrence of hypernasality and hyponasality in the same speaker usually

as the result of incomplete velopharyngeal closure in the presence of high nasal resistance that is not sufficient to block nasal resonance completely" (page 190).

This study focuses only on the abnormal pattern of speech described as hypernasal resonance. Terminology, definitions, and tools for perceptual and instrumental assessment of hypernasal resonance are presented next and in the following chapter.

Hypernasality

The phenomenon of hypernasality has been addressed in the literature by different names (Table 1). Not only a large variety of terms are available for this single phenomenon but also a variety of definitions. While defining hypernasality authors have ranged from a simplistic approach, such as that provided by Shames and Wiig who described hypernasal resonance as "that quality of speech produced by too much nasal resonance" (page 464, 1986), to detailed, such as that provided by McWilliams and colleagues who defined hypernasality as follows:

> a phenomenon associated primarily with vowels, which are differentially affected by the shift from a primary laryngeal-pharyngeal-oral system to a laryngeal-pharyngeal-nasal-oral system, with the competing oral and nasal cavities both playing roles in the resonating aspects of speech and serving to alter the acoustic signal so that its spectrographic characteristics are changed and the auditory perception of the signal is recognized as different. (pg. 255, 1990)

Table 1
Terminology Associated with the Phenomenon of Hypernasality

TERM	CITATION
• Hypernasality	Case (1996, pg. 316); Aronson (1990, pg. 198); McWilliams et al. (1990, pg. 255); Baken (1987, pg. 393); Shames and Wiig (1986, pg. 464); Bzoch (1989, pg.180); Massengill (1972, pg.16)
• Hypernasal Resonance	Bzoch (1979, pg. 180); Nicolosi et al., (1983, pg. 258)
• Nasality	Case (1996, pg. 316); Baken (1987, pg. 393);Bzoch (1979, pg. 180); Massengill (1972, pg. 16-17), Travis (1971, pg.538)
• Nasalization	McWilliams et al. (1990, pg. 255); Baken (1987, pg. 393)
• Nasalized Consonant	McWilliams et al. (1990, pg. 274)
• Hyperrhinolalia	Case (1996, pg. 316); Aronson (1990, pg. 198)
• Hyperrhinophonia	Case (1996, pg. 316)
• Rhinolalia Aperta	Case (1996, pg. 316); Aronson (1990, pg. 198)
• Oral-Nasal Balance	McWilliams et al. (1990, pg. 255)
• Nasalance	McWilliams et al. (1990, pg. 255)
• Open Nasal Speech	Massengill (1972, pg. 17)
• Open Nasality	Aronson (1990, pg. pg. 198); Hirschberg et al., 1995, pg. S118)
• Nasal Voice Quality	Massengill (1972, pg. 16)
• Assimilated Nasality	Case (1996, pg. 316)

Despite variations in terminology and definition, hypernasality is generally associated with the perception of excessive, undesirable, or unacceptable nasal resonance (Baken, 1987; Case, 1996; Nicolosi, Harryman, & Kresheck, 1983). The elements of speech distorted by this condition can include both vowels and voiced consonants (Aronson, 1990; Baken, 1987; Bzoch, 1989; Nicolosi, et al., 1983).

Even though defined as a deviant speech resonance condition, hypernasality is usually approached as an atypical and inappropriate speech symptom directly related to velopharyngeal(VP) function. During management and study of hypernasal speech, however, it is important to consider not only the VP mechanism as the probable source of hypernasality and its associated symptoms. As Witzel (1995) has stated:

> in most cases hypernasality results from inadequate closure of VP valve during speech, but it may also be caused by the entrance of air into the nasal cavity through an open palate or fistula in the hard or soft palate . . . other subtle factors also need to be considered, such as tissue mass and elasticity, structural deviations in the nose, constriction or tension in the vocal tract, mouth opening, respiratory efforts, tongue movements, timing of VP closure in relation to laryngeal, lingual and labial movements for speech, and nasal resistance (Witzel and Stringer, 1988). (page 145)

The dynamics of the speech production mechanism indicate the possibility of interaction between the VP valve and other structures within the speech system (Bzoch, 1989; McWilliams et al., 1990; Witzel, 1996). It is not surprising to find, therefore, that hypernasality often occurs in association with the presence of weak pressure consonants, nasal air emission, as well as atypical compensatory articulation. Identification of the source of hypernasality and its associated symptoms involves a complex diagnostic process. However, it is not within the scope of this study to discuss and to address all speech features that can possibly be associated with the presence of hypernasal resonance. Only the tools designed for perceptual and instrumental assessment of hypernasal speech will be discussed.

Assessment of Hypernasality

Identification and quantification of hypernasality are the responsibility of the Speech-Language Pathologist (SLP) on many rehabilitation teams. The effectiveness of SLPs in discriminating between normal and disordered speech nasality, as well as in evaluating treatment related changes, guides decisions at every step of the rehabilitation process. The tools available to SLPs during management of hypernasality are auditory-perceptual judgments and instrumental analyses of speech involving some type of signal processing technique.

While most clinicians might agree regarding the presence or absence of hypernasality, consistent agreement while rating amounts of speech nasality is more difficult. Use of instrumental measures to corroborate clinical judgments of speech deviations and to more appropriately document perceptual impressions of nasality seems to be one way of overcoming the limitations of perceptual assessment. That is, while helping to characterize acoustic correlates of perceived nasality, instrumental measures could provide means for the definition of fixed references for perceptual standards against which these same instrumental tools could be validated.

Statement of a Problem

Contemporary research seems to be converging towards refinement of perceptual and instrumental tools for measuring

several aspects of speech. Investigators and clinicians are becoming more aware of the strengths and weaknesses of both of these methods. As described by Kent (1996), "auditory-perceptual methods carry strong advantages of convenience, economy, and robustness, but it is also clear that these judgments are susceptible to a variety of sources of error and bias" (page 7). Kent continues reporting that:

> one way of overcoming the limitation of perceptual analysis of speech or voice is to supplement perceptual ratings with instrumental (acoustic or physiologic) analyses of the same behavior. Presumably, the instrumental methods would offer a greater reliability and perhaps improved precision. But the potential value of instrumental procedures is still being proved. A brief examination of selected acoustic methods reveals the obstacles to an efficient combination of perceptual and instrumental methods. (pages 17-18)

The clinical reality during the assessment of hypernasality seems to fit Kent's description: as convenient, economic, and robust as current methods for perceptual assessment of hypernasality might be, clinicians still lack a standard procedure that can be reliably used from assessor to assessor. On the other hand, the use of instrumental measures to supplement perceptual assessment of hypernasality is also questionable: many studies have shown only a poor relationships between instrumental and perceptual measures of hypernasality (see chapter 2).

The need for research on the relationship between perceptual and instrumental measures is critical if one is to follow the current trend in the field of communication disorders towards valid and reliable treatment efficacy research. This study, therefore, was designed with the broad

purpose of verifying the relationship between perceptual and instrumental measures of hypernasality currently in use at craniofacial centers around the world. A review of the pertinent literature as well as identification of a specific research question are presented in the following chapter.

CHAPTER 2
REVIEW OF LITERATURE AND RESEARCH QUESTION

Perceptual Measures of Hypernasality

Speech-language pathologists (SLPs) have traditionally relied on perceptual tests to identify the existence of hypernasal resonance disorder. Perceptual tests involve the use of human auditory skills to yield impressions of certain characteristics of an individual's speech. The use of perceptual tests involves subjective judgments of quality determined by simply listening to the patient's speech, unaided by any system(s) of physical measurement (Fletcher, Soodi, & Frost, 1974).

Even though most SLPs agree that perceptual judgments are the most basic and important diagnostic tools available (D'Antonio & Scherer, 1995; Kent, 1996; McWilliams et al., 1990; Moon, 1993), perceptual tests lack standardization. More specifically regarding hypernasality, a variety of perceptual measures exist and their use appears to be based primarily on clinician preference rather than on how reliable and valid perceptual tools may be.

Perceptual measures described in texts treating the topic of resonance disorders include categorical ratings, paired comparisons, and numerical rating scales. While using

categorical ratings, the clinician is required to assign an unordered, nominal category (e.g. "normal" or "hypernasal") to a sample of the patient's speech. That is, only the identification of the presence or absence of hypernasality is possible with this type of perceptual assessment.

For measures using paired comparisons, the clinician compares two speech stimuli to each other, and rates identified differences toward some direction (e.g., such as rating whether the first stimuli is greater or lesser in nasality than the second). During use of numerical rating scales judges are required to assign a number between 1 and "n" to a sample of the patient's speech, where "n" represents the maximum point of deviation/impairment on the scale.

Among the different types of perceptual tests currently in use to assess hypernasality, the measures most often reported are basically two: a) variations of numerical rating scales, and b) variations of paired comparison tests, usually called "cul-de-sac tests". The basic difference among these two types of measures is that while numerical scales presumably allow judges to rate degrees of hypernasality, cul-de-sac tests provide an index as to the presence or absence of excessive nasal resonance.

Regardless of the clinician's choice of perceptual test a number of assumptions underlie the clinical applicability of perceptual ratings of any aspect of speech. As Kent (1996) described:

> clinical application of auditory judgments are predicted on the assumption that listeners (a) have a common

> understanding of perceptual labels such as hoarse, nasal, rough, monoloud, excess and equal stress, or stuttering; (b) use essentially the same verbal descriptors and associated scale values to assess a given sample of speech or voice; (c) can isolate for judgment one perceptual dimension from several co-occurring dimensions; (d) have uniform reliability in judging the various dimensions that give a complete clinical portrait of speech or voice disorders; (e) can make perceptual judgments for which the interjudged differences are smaller than the differences needed for clinical classification or to discern changes in clinical status. (page 7)

The meaningfulness of the ratings obtained with the use of auditory-perceptual tests, therefore, seems to rest not only with the consistency with which these tests are used, but also with the clinical reality and knowledge base with which a disorder is classified and measured by the group of specialists in each specific field. From this broad point of view Kent (1996) lists some of the limitations to auditory-perceptual testing:

> 1) judges do not appear to have equivalent definitions of the dimensions to be rated; 2) specialists fail to reach consensus on which perceptual dimensions should be rated for a given disorder; 3) perceptual ratings of various dimensions are inter-correlated, that is, they are not independent. When this happens, the values obtained for any one dimension may be influenced by co-occurring dimensions of a disorder; 4) various perceptual dimensions are not rated with uniform reliability; 5) differences among expert judges are larger than the differences needed for diagnostic classification or the effects of intervention. (pages 7 & 8)

Not surprisingly, therefore, professionals in the field of resonance disorders disagree not only regarding the choice of perceptual test but also regarding the validity and reliability of each perceptual tool. In general these tests are not standardized nor highly regarded as reliable or valid

either as clinical or research tools (Gerratt, Kreiman, Antonanzas-Barroso, & Berke, 1993). Review of the most frequently reported perceptual tests and their limitations for assessment of hypernasality follows.

Numerical Scales

Equal-appearing interval scales have been the most frequently used scales when a perceptual assessment of severity/degree of hypernasality is desired. These scales vary largely regarding their grading point interval system, with the most commonly used scales for rating hypernasality usually involving five or seven point intervals (McWilliams, et al., 1990). With equal-appearing interval scales the lowest point usually represents speech that falls within acceptable limits, while the uppermost point represents the most severe form of hypernasality. The assumption that the points on the scale are equidistant has to be made for measurements to be treated as equal interval levels so parametric statistics can be applied (Kreiman, Gerratt, Kempster, Erman, & Berke, 1993).

Independently of the choice of any specific grading point interval, the results reported with the use of numerical scales are often associated with unacceptable or questionable intra- and inter-judge reliability. The variability reported during use of these scales can be associated to the consistency with which listeners use perceptual scales.

Listeners' related variability. Human auditory processing might partly explain the lack of consistency reported during use of numerical scales in auditory-perceptual judgments of hypernasality. Baken (1987) for example, suggests that the

> . . . major problem with simple listening as a diagnostic method is that the auditory system is inherently configured for dealing with the speech signal as a whole entity and for detecting linguistically relevant features in it . . . auditory processing {therefore} often does not leave the listener with a conscious awareness of the acoustic details that have {been} combined to generate a given perception. (page 1)

Fletcher, Sooudi and Frost (1974) have more simplistically stated that the human ear seems to process incoming speech in words or phrases rather than in individual sounds or sound features. These authors suggest that during assessment of speech nasality the examiner also needs to consider the fact that some nasality is naturally present during speech, and that nasality varies from speaker to speaker, and in part as a function of region and language. Therefore, asking listeners to isolate a single sound feature and to give it a rating of a specific level of severity may be a task more complex than it seems.

Can we try to further explain the variability usually associated with the use of perceptual tools with the fact that each individual has his/her own unique standards against which to judge nasality? Recently, Kreiman, Gerratt, Kempster, Erman and Berke (1993) discussed the existence of "internal standards or scales" against which listeners

compare stimuli presented for perceptual ratings of certain quality of voice. As Kreiman and colleagues reported,

> several factors are involved in mapping an acoustic signal onto a voice quality rating. The first is the acoustic voice signal being rated. Most studies of voice quality in the literature apparently assume that mapping between physical signals and psychological qualities are a constant, linear process and thus treat any variation in rating as random error by raters. However, our findings indicate that several consistent and thus potentially controllable factors also contribute to observed voice ratings . . . These factors include listeners' experience with voices (which will shape their particular internal standards for the voice being judged), their individual perceptual habits and biases (Kreiman at al., 1990; Kreiman et al., 1992), and presumably overall sensitivity to the quality being judged . . . Additional factors related to listeners include fatigue, attention lapses, and mistakes. (page 32)

Sources of errors and bias during perceptual assessment of nasality appear to go beyond the listener's ability (or lack of) in making reliable perceptual judgments of these aspects of speech. Nasality, as described in the literature, can vary in relation to many factors. Bzoch (1989), for example, reported that:

> the general impression of hypernasality in the speech of a patient is related to mode of phonation, precision of articulation of consonant sounds, age and sex, the general fundamental frequency of voice, the speech sample studies, the rate of articulation of speech, the subject's level of fatigue or anxiety, and to velopharyngeal insufficiency. (page 163)

Yet the number of listeners involved, the use of live vs. recorded speech samples, the use of backward vs. forward play, and the phonetic makeup of the speech sample elicited all can be contributing factors for variations in perceptual ratings (Counihan and Cullinan, 1970; D'Antonio & Scherer, 1995; McWilliams et al., 1990). Furthermore, many SLPs have

to conduct their perceptual assessment in noise environments, and may lack training and/or calibration while using perceptual scales.

When considering all the shortcomings of using numerical scales for perceptual assessment of degrees of hypernasality, it seems risky to assume that listeners can consistently assign a value (number) to their perception of a certain degree of nasality. Many professionals have opted for the use of screening perceptual tools designed only to provide an index of the presence or absence of hypernasality. As Bzoch, for example, reported:

> only if the term hypernasality is defined and strictly limited in use to refer to the detectable distortions of syllabic elements in speech due to the effects of atypical coupling of the nasal resonating cavities produced under conditions of clear phonation and normal articulation can hypernasality be reliably identified or logically discussed in clinical or speech science research . . . Hypernasality, as defined, can be reliably demonstrated to be either present or not present. Only a combination of evidence from pre- and post- treatment clinical nasal emission and hypernasality resonance test measures and from instrumental tests (described in this book) should be considered as adequate verification that hypernasality has been actually managed satisfactorily. (1989, pages 163 and 164)

Even though cul-de-sac tests lack information regarding degrees of nasality, the perceptual context provided with these tests certainly reduces the burden placed upon listeners' perceptual internal standards. That is, while rating the outcome of a cul-de-sac test, listeners make their judgments by comparing one production to another rather then by comparing a subject's production to their own internal standards.

Cul-de-sac Tests

The use of cul-de-sac tests for screening the presence of hypernasality was reported as early as 1913 by Gutzman (cited in Haapanen, Heliovaara & Ranta, 1991). Cul-de-sac tests follow the principle of paired comparison tests in which two stimuli are compared to each other as same or different but not further rated as being greater or lesser than each other. These tests involve the creation of a nasal cul-de-sac resonance cavity. That is, when the speaker's nares are pinched closed and the VP port is open a bifurcated nasal-oral resonance tube can be formed. And as Bzoch (1989) described:

> the abnormal effects of nasal resonance on syllabic elements {can be} exaggerated by alternately closing and opening the nares {of a speakers during production of oral sounds}. This changes the nasal cavity alternately from an open into a cul-de-sac resonator while the patient repeats vowel sounds or words. (page 164)

During a cul-de-sac test the presence of an open VP valve or a palatal fistula, for example, would explain the perception of a shift/difference in resonance quality between the nares open and the nares closed conditions. That is, displacement of sound energy into the nasal cul-de-sac resonance cavity is expected to result in a perceivable acoustic difference between the first (open nares) versus the second (closed nares) stimuli. During cul-de-sac testing, therefore, the nares open condition provides the context against which the nares closed condition is compared. Even when a difference (shift in resonance quality) is noted

between both conditions, no grading of the difference is involved. Two variations of cul-de-sac tests have been described in the literature: one involving the use of prolonged vowels (McWilliams, et al. 1990; Moon, 1993) and the other involving the use of single words (Bzoch, 1989).

Cul-de-sac test during vowel production. The clinical procedure for cul-de-sac testing with isolated vowels requires having the speaker sustain the production of a vowel, typically /i/ or /u/, while the clinician alternately opens and closes the patient's nares. A perceptual judgment is made as the clinician listens for shifts in the resonance quality throughout the prolongation of the sound. When a shift of resonance quality is heard the test is rated positive. Positive cul-de-sac is interpreted as an indication of the presence of excessive nasal resonance.

Although cul-de-sac tests during prolonged vowel production still are used as a screening tool in many countries (e.g., Brazil and Paraguay), this measure does not seem as popular in North America or Northern Europe (e.g., USA, Canada, and Sweden). This reduction in the clinical use of the cul-de-sac test with sustained vowels could be based upon the findings of several studies which verified that many normal speaking subjects produce vowels with incomplete VP closure (Williams, 1989). Furthermore, as Williams (1989) continues,

> considerable research has revealed that the functioning of the VP port during an individual's production of isolated sustained sounds is not necessarily predictive

> of how the VP port functions during connected speech. (page 197)

As an alternative to assessing cul-de-sac during isolated sustained vowel production, Bzoch (1989) developed a cul-de-sac measure of hypernasality during production of single words.

Cul-de-sac test during single word production. Bzoch (1989) described that the hypernasality test during production of single words involves

> a set of 10 one-syllable words, each beginning with a /b/ and ending with a /t/. The syllabic elements in the words selected sample the vowel triangle from high-front to low-back to high-back tongue positions for vowels. The purpose of the test is to yield a base ten count of the frequency of occurrence of hypernasal resonance on single words with vowels in a plosive environment. These should always have no nasal resonance under conditions of normal velopharyngeal valving. The syllabic elements are initiated and closed off by pressure consonant sounds, a condition which predisposes to complete velopharyngeal seal and no nasal resonance in normal speech production. (page 146)

As the speaker produces each word twice, the clinician pinches the nares closed during the second production, changing the open nasal resonator into a cul-de-sac or "dead-end" resonator. If hypernasality is present a shift in resonance is expected during the nares closed conditions. Bzoch (1989) continues explaining that

> a perceptual judgment is made by the tester comparing the quality of the first and the second utterances. Words that shift in quality under the second cul-de-sac resonance condition are circled on the recording form . . . {and} since the clinical hypernasality test enhances the tester's perception of the presence of hypernasal resonance by shifting formants and creating a greater distinction between oral and nasal syllables, it is particularly useful for use in the often noise environments prevalent during cleft palate team clinical speech evaluations. (page 146)

The Bzoch hypernasality cul-de-sac test is proposed as part of a standard battery of five perceptual tests, and is designed to yield "reliable test data to infer judgments regarding the adequacy or inadequacy of velopharyngeal function for speech" (page 144, 1989). This test is currently used at the University of Florida Craniofacial Center during screenings of patients' VP function.

Some authors have discussed limitations of cul-de-sac testing. McWilliams and her colleagues (1990), for example, reported inconsistencies with the test protocol, such as identifying shifts in resonance even in patients that do not sound hypernasal during conversation. As speakers may be able to manipulate their VP valve to an open condition even when able to achieve closure, it is possible to change the nasal cavity of most normal speakers into a cul-de-sac resonator, creating therefore a shift in resonance quality even when hypernasal resonance is not identified during conversational speech.

Although cul-de-sac testing is a simple procedure, a brief training session of subjects and several repetitions of the test are desirable. Before testing begins it should be verified that the subject can breath nasally, and nasal cleansing such as nose blowing may be necessary (Bzoch, personal communication, 6-12-96), to avoid the opposite result of not creating a shift of resonance in those individuals who do present hypernasality. It is also important to note that the presence of mixed resonance (i.e.

some cases of pharyngeal flap with minimal lateral pharyngeal wall movement) or the presence of a completely open cleft palate (i.e. unoperated adult speaker) could result in a false negative by preventing the creation of the nasal cul-de-sac resonator. A cul-de-sac test, therefore, can only provide an index of the presence of hypernasality, which in some cases might not be obtainable even when hypernasality is heard during the individual's conversational speech.

Notwithstanding the fact that the cul-de-sac test during production of words overcomes the limitations associated with isolated vowels, still the complexity involved with production of single words is less than that involved with conversational speech. While it could go without saying that the result of a cul-de-sac test is biased by its own limitations, it seems applicable to recall here that it can also be biased by listeners' limitations during perceptual ratings. Therefore, listeners' ability and consistency in discriminating shifts in resonance quality can also be a source of variability while using cul-de-sac tests. This is where an instrumental analysis of the speech signal may play an important role.

Instrumental Assessment of Hypernasality

Clinicians generally agree that regardless the choice of perceptual test (numerical scale or cul-de-sac), instrumental measures can substantiate/supplement their perceptual impressions of nasality. Three instrumental procedures

involving signal processing techniques can be used for acoustic assessment of speech nasality: sound spectrography, accelerometry, and sound pressure techniques. Of the three, sound pressure techniques have been the most thoroughly investigated and are the ones addressed in this study.

Development of techniques involving sound pressure measurements and their application in the field of resonance disorders are based upon the properties of nasalization. As reported by Lass (1996), nasalization, whether during normal production of nasal sounds or during hypernasal production of oral sounds, has been associated with a reduction in the overall acoustic energy because of damping by the nasal cavity. An interaction between oral and nasal cavities, therefore, affects the acoustic output

> not only through the length of the tube but also through the shape and tissue quality of the passages . . . the soft and the convoluted mucous membranes of the nasal cavity absorb sound . . . the general result of these interactions is a reduction in the overall energy of the vowel and a widening of the formants bandwidths. (Lass, 1996, page 197)

As changes in oral-nasal energy seem to be a major feature for distinction of nasality, some authors have attempted to distinguish between normal or deviant nasalization by comparing measurements of amount of acoustic energy radiated through the mouth and nose. Fletcher (1970) proposed using oral and nasal sound intensity measures as an index of hypernasality.

Fletcher's efforts to characterize the physical attributes of speech associated with the perception of

nasality resulted in the development of TONAR - The Oral Nasal Acoustic Ratio (1970), later improved as TONAR II. With TONAR, ratings of degrees of speech nasality could be estimated from the ratio between oral and nasal sound pressure measures as recorded simultaneously from the oral and nasal cavities during speech production.

TONAR II. TONAR II included a microphone-sound separator system with two lead chambers that permitted separation of the sounds transmitted from the nose and mouth. The chambers contained microphones positioned to pick up the nasal and oral acoustic signals produced during speech. With this instrument the nasal signal was compared with the combined nasal plus oral signals, resulting in a score termed "nasalance". As an instrument introduced to analyze the nasal quality of the acoustical signal, TONAR II had limited clinical application. According to Dalston (in press), TONAR's microphone-sound separator system had limitations regarding both sound dampening and orientation of the sound separator and subject's face. Improvement to the TONAR system resulted in the development of the Nasometer, an instrument with slight differences in structure, function and practical features (Kay Elemetrics, 1987)

Nasometer. Technological advances led to the development of TONAR's system into what is currently commercially available as the Nasometer (Kay Elemetrics Corporation, Pine Brook, NJ). The Nasometer is a micro-computer based acoustical instrument with an input sound separator assembly

consisting of a metal plate, a headgear to support the plate, a nasal microphone attached on top of the plate, and an oral microphone attached under the plate. Measurements of sound pressure levels are derived from acoustical input from both microphones. The Nasometer amplifies and filters the signals from each microphone, converting them from analog to digital, and computes a numeric ratio of nasal acoustic energy to the sum of nasal plus oral acoustic energy. This ratio is termed "nasalance score", as suggested by Fletcher (1978), differentiating it from the perceptual term "nasality".

Clinical Application of Nasometry

Review of the literature indicates that since the Nasometer became commercially available as a standard system, it has quickly gained widespread usage in several languages and for an array of clinical populations. References on the use of the Nasometer with speakers of languages other than English have been found for Brazilian Portuguese (Dalston, Trindade, & Genaro, 1994; Pegoraro-Krook, Bzoch, Dutka, Williams, Seagle, & Marks, 1994), Canadian French (Leeper, Rochet, & MacKay, 1992), German (Heppt, Westrich, Strate, & Mohring, 1991; Stellzig & Komposch, 1994), Finnish (Haapanen, 1992; Haapanen, Ignatius, Rinkanen, & Ertama, 1994), Chinese (Luo-Y, 1992), Spanish (Gonzalez-Landa, Santos-Terron, Miro-Viar, & Sanchez-Ruiz, 1990; Santos-Terron, Gonzalez-Landa, & Sanchez-Ruiz, 1991; Anderson, 1992), and Arabic (Motlak, 1992).

Nasometry has been included in assessment/research protocols for management of velopharyngeal dysfunction (Dalston, Warren, & Dalston, 1991a; Haapanen, 1992; Haapanen et al. 1994); nasal obstruction and airway changes (Dalston, Warren, & Dalston, 1991b; Parker, Clarke, Dawes & Maw, 1990; Riski, Pegoraro-Krook, Dutka, Kattos, Rosseto, 1995; Trindade, Silva, Suguimoto, & Trindade, 1995; Williams, Eccles and Hutchings, 1990); speech of the hearing impaired (Tatchell, Stewart, & Lapine, 1991; Lapine, Stewart, & Tatchell, 1991); and voice disorders (Hirschberg, Dejonckere, Hirano, Mori, Schultz-Coulon & Vrticka, 1995).

Finally, several studies have looked at the relationships between nasalance scores and factors such as gender (Litzaw & Dalston, 1992; Kavanaugh, Fee, Kalinowski, Doyle, & Leeper, 1994; Pegoraro-Krook et al., 1994), age (Seaver, Dalston, Leeper, & Adams, 1991; Hollister, Seaver, Sandridge, & Andrews, 1992; Marsho, Flahive, & Naas, 1992; Pegoraro-Krook et al., 1994), race (Mayo, Floyd, Warren, Dalston & Mayo, 1996), dialect and language (Santos-Terron et al., 1991; Leeper et al., 1992; Dalston et al., 1993;), articulatory skills (Hashimoto, Watterson, & Paynter, 1992), vocal loudness (Watterson, York, McFarlane, 1994), and speech sample (Dalston & Seaver, 1992; MacKay & Kummer, 1994; Karnell, 1995; Watterson, Hinton, McFarlane, 1996).

The search for an objective tool to quantify degrees of hypernasality appears to be the main reason for inclusion of nasometry in the clinical or research protocols of most of

the articles cited above. Using nasometry to meet such an objective, however, undertakes the assumption that nasalance scores offer a valid, quantifiable measure of perceptually identified hypernasality. That is, if the instrumental measure (Nasometer) is not validated against perceptual measures of nasality, the objective quantification of hypernasality obtained with nasalance scores becomes questionable.

Although the Nasometer has been extensively used, the relationship between nasalance scores and perceptual ratings of nasality still is unclear. As this study addresses this issue, review of measures indicative of the relationship between the two variables and review of the limited literature discussing the relationship between nasalance and nasality are provided next.

Relationship between Nasalance and Nasality

Relationship between two variables can be expressed statistically with a correlation coefficient. As Williams describes (1986), the statistical procedure of correlation "characterizes the existence of a relationship between variables {and} ... although there may be many reasons for a relationship, correlation says nothing about these reasons" (page 125). A correlation coefficient, *r*, as Williams continues, provides an index of the magnitude and the direction of a relationship. Such an index is expressed according to the following scale (Williams, 1986):

+1.0 (perfect positive correlation)
0.0 (no correlation)
-1.0 (perfect negative correlation)

While discussing correlation, Marks (1982) explained that such a coefficient measures the linear relationship between two variables. He says that a positive correlation,

> implies a positive relationship between X and Y: that is as X increases, Y also increases. A similar statement applies to a negative correlation. A correlation coefficient of +1 means that all the data points lie on a straight line with a positive slope. A similar statement can be made for a correlation of -1. A correlation coefficient of 0 implies that a line with no slope is the best fit to the data: there is no linear change in Y as X changes. (page 162)

Additionally, while reporting correlation coefficients, the statistical procedure of hypothesis testing can be used to verify the significance of a given value of correlation. With this procedure the research hypothesis usually states that the variables are related, while the null hypothesis states that no correlation exists, all within a pre-set significance level (e.g. $p <.05$). However, Williams (1986) has noted that "the fact that the correlation is statistically significant . . . does not mean that it is necessarily meaningful" (page 130). Further interpretation of magnitude and direction of the relationship between the variables is warranted, even though it is often a subjective matter (e.g. a relationship considered high in one situation may be considered negligible in another). While the implication of a coefficient, not only its magnitude, may be interpreted by the researcher, consistency of terminology in describing the magnitude of the coefficient might help in

interpreting the results. Guilford, as cited in Williams (1986, page 132), suggested the use of the following scale during interpretation of correlation coefficient:

<.20	slight; almost negligible relationship;
.21-.40	low correlation; definite but small relationship;
.41-.70	moderate correlation; substantial relationship;
.71-.90	high correlation; marked relationship;
>.90	very high correlation; very dependable relationship.

Correlation analysis has been reported for most of the studies discussing the relationship between perceptual measures of nasality and nasalance scores (Dalston, et al. 1991a; Dalston & Seaver, 1992; Dalston, et al., 1993; Nellis, Nieman & Lehman, 1992; Paynter, Watterson, & Boose, 1991; Watterson, McFarlane, & Wright, 1993; Watterson et al., 1996). According to Guilford's scale, none of the coefficients reported in these studies (see Table 2) revealed a very high correlation between nasality and nasalance, which would have been indicative of a very dependable relationship between both measures; yet all coefficients in these studies were within a moderate-high correlation range (.40 - .90), denoting either a substantial or a marked relationship.

Interpretation of correlation coefficients has been as variable as the scores themselves (see Table 2). For instance, while some authors (Dalston et al., 1991a; Dalston and Seaver, 1992; Dalston et al., 1993; Watterson et al.,

1996) seemed encouraged about clinical use of nasalance scores as indexes of nasality, other investigators have questioned the use of nasalance as a predictor of perceptually identified abnormal resonance (Nellis et al., 1992; Paynter et al., 1991; and Watterson et al., 1993).

Correlational analysis, however, has not been the only measure reported in studies discussing the relationship between nasality and nasalance. Dalston and colleagues (1993) have noted that correlational analysis

> may not be the most appropriate technique for determining the value of nasometry for assessing oral-nasal resonance balance . . . {rather} prediction analyses appeared to be more useful in determining the clinical utility of the Nasometer. (page 288)

Prediction analysis (see Table 3) reported by Dalston and colleagues (1993) and others (Hardin, Van Demark, Morris, & Payne, 1992; Stellzig et al., 1994; Dalston et al., 1991a; Dalston et al., 1993; Paynter et al., 1991; Watterson et al., 1993; Watterson et al., 1996), refers to indexes of sensitivity and specificity of diagnostic tests.

Feinstein (1977) reported that, as early as 1947, the terms sensitivity and specificity were introduced by Yerushalmy, as statistical indexes of the efficiency of a diagnostic test. According to Feinstein,

> the sensitivity of the test would indicate its capacity for making a correct diagnosis in confirmed cases of the disease {condition}. The specificity would indicate the capacity for correct diagnosis in confirmed negative cases. These concepts need not be restricted to diagnostic tests alone and can be applied to a variety of tests used for identifying clinical conditions, {therefore} sensitivity would be the number of true positive cases divided by the number of confirmed positive cases, which is the sum of true positive plus

Table 2

Summary of the Studies Reporting Correlation Coefficient to Indicate the Strength of the Relationship between Perceptual Ratings of Hypernasality and Nasalance Scores

Articles	*r*	Guilford's Scale (page 19)	Authors' Interpretation/Comments
Dalston et al., 1991	0.82	HIGH correlation; marked relationship;	"...we have been impressed with the extent to which the nasometer coincides with independent clinical assessments of hypernasal resonance" (page 187)
Nellis et al., 1992	NOT significant		"the correlation between ratings of hypernasality and nasalance scores failed to reach significance" (page 159)
Paynter et al., 1991	0.66	MODERATE correlation; substantial relationship	(cited in Hardin et al. 1992, page 348)
Watterson et al., 1993	0.49	MODERATE correlation; substantial relationship	"the obtained relationship (r=0.49) was not sufficient to inspire clinical confidence in nasalance measures" (pg 23); "on a clinical basis, these findings suggest that nasalance is not a good predictor of hypernasality" (page 23)
Dalston & Seaver, 1992	0.81	HIGH correlation; marked relationship;	not discussed as the study was not designed to measure such a relationship
Dalston et al., 1993	0.78	HIGH correlation; marked relationship;	"among the three center involved in the current investigation, the correlation between hypernasality and nasalance scores was modest at best" (page 288);
Waterson et al., 1996	0.70 - Zoo 0.51-Turtle	MODERATE correlation; substantial relationship	"...clinicians can be most confident of nasalance scores for patients who are obviously normal or obviously hypernasal ...should have least confidence in nasalance scores for patients who are borderline-normal" (page 72)

Table 3

Summary of the Studies Reporting Sensitivity and Specificity Indices Indicative of the Capacity of the Nasometerto Confirm the Presence or Absence of Hypernasality Perceptually Identified

Articles	Sensitivity	Specificity	Authors' Interpretation/Comments
Dalston et al., 1991 (cut-off: 32%)	0.89	0.95	"these scores were quite accurate in categorizing patients in a manner similar to that of the senior author" (page 186)
Paynter et al., 1991 (cut-off: 25.25%)	0.78	0.63	(cited in Hardin et al. 1992, page 348)
Hardin et al., 1992 (cut-off 32%, 26%, and 2 SD of norms)	0.57 0.76 0.57	0.91 0.85 0.91	"nasometry should not be used as substitute for reliable clinical judgments ...nasometer may provide valuable information" (page 350)
Watterson et al., 1993 (cut-off 25.25%)	0.71	0.55	"Nasometer not only had difficulty discerning degrees of hypernasality, but also had difficulty separating normal speech from hypernasal speech" (page 23)
Dalston et al., 1993 (cut-off 28%)	0.87	0.86	"the correspondence between nasometer output and clinician assessment is not exact" (page 288); "it is our belief that the results of this investigation suggest that ... the nasometer is able to reflect the judgments of experienced clinicians" (page 290)
Stellzig et al., 1994 (in German language)	0.80	1.00	"our results, which correspond almost exactly to those obtained in Anglo-American studies, demonstrate that also in german-speaking countries the nasometer can be a reliable instrument for diagnosing hypernasality" (Abs.)
Waterson et al., 1996 (Zoo - cut-off 22%) (Turtle - cut-off 22%)	0.72 0.83	0.50 0.50	"disagreements {between listeners and Nasometer} represented borderline cases where either nasality rating or nasalance measure crossed over the cutoff from one stimulus passage to the other" (page 72)

> false negative cases, {while} specificity would be the number of true negative cases divided by the total number of confirmed negative cases, which is the sum of true negative plus false positive cases. (page 214)

Feinstein also suggested that interpretation of these indexes is related to the purpose for which the test is used. Generally, as he described, "diagnostic tests are employed at least for three different purposes, : discovery, confirmation, and exclusion . . . {and} the statistical indexes of efficiency should be arranged accordingly" (page 111). With these indexes, the relationship between the clinical condition (such as perceptually determined hypernasality) and the test result (such as instrumentally determined nasalance score) needs to be dichotomously described. When the condition being measured is not dichotomously described (such as *present* or *absent* hypernasality), the researcher needs to identify arbitrary lines that determine the dichotomous break points of the data. Different levels of dichotomization, therefore, will generate different sets of values for sensitivity and specificity.

For most of the studies discussed above, "break points" have been described as nasalance cut-off scores while referring to the measure of nasalance (for example a nasalance score of 32%), and as a certain grading point of a rating scale while referring to the perceptual measure of nasality (such as 2 on a six-point equal-appearing interval scale). Feinstein (1977, page 219) noted that such dichotomous arrangement may create "gross and often erroneous

oversimplification of the reality of clinical diagnosis". However, it is a necessary arrangement when describing the relationship between two variables (e.g. nasality and nasalance) by means of efficiency measures.

Like the results of studies reporting the use of correlational analysis for establishing the level of relationship between nasalance and nasality, the results of studies involving the use of prediction analysis were not consistent across investigations either (Table 3). As sensitivity and specificity scores have varied from study to study, so have the interpretation of authors regarding clinical usefulness of the Nasometer. Therefore, neither correlational nor predictive analyses seem to indicate that the relationship between nasalance and nasality is consistent across studies. Differences in methodological procedures may have contributed to such inconsistencies among reported scores.

<u>Different Speech Samples Within Studies</u>

It is interesting to note that not all studies discussed above obtained measures of nasality from the same speech samples from which the measures of nasalance were obtained. That is, simultaneous recordings of nasometric and perceptual speech samples have not been the procedure adopted in all studies reporting measures of relationship between nasalance and nasality. While Nellis and colleagues (1992) and Watterson and colleagues (1993), for instance, used samples of speech simultaneously recorded to verify the relationship

between nasalance and nasality, Dalston and colleagues (1991a), Hardin and colleagues (1992), Dalston and colleagues (1993) used samples not only recorded independently but also involving different stimuli from that used during nasometric recording. While these studies had different purposes --to obtain a measure of relationship or to identify the utility of the instrument during the clinical decision process-- different purposes may explain choices of different methodological procedures, but they also limit the power of correlating instrumental analyses of one behavior to the perceptual analyses of another.

Reliability of Perceptual Measures

Studies varied largely regarding how perceptual ratings of speech nasality were obtained. The number and the interpretation of scales grading points for measuring the degree of nasality, for example, was different from study to study. While Dalston and colleagues (1991a) and Nellis and colleagues (1992) reported using 6-point rating scales, Watterson and colleagues (1993) used a 5-point scale, and Hardin and colleagues (1992) used a 7-point scale. The choice of different intervals seems to be arbitrarily based on clinician preference as does the choice of break points used for dichotomous representation of perceptual data. In Dalston and colleagues (1991a) perceptual ratings of 3 or greater were used as threshold/limit for identification of presence/absence of hypernasality. While in Hardin and

colleagues (1992) ratings of 2.5 or greater were interpreted as indicative of hypernasality.

One could argue here that even when all of these studies are taken as a group, differences in scaling as well as interpretation of data might become the primary source of variability responsible for the differences in levels of correlation among the studies. Therefore, besides taking into account intra-judge variability (e.g. Is each judge using the same scale consistently across subjects?) and inter-judge variability (e.g. Are different judges rating the same behavior consistently?), we also would have to consider the possibility of interstudy variability (e.g. To which degree are different scales equivalent?).

Statement of Purpose

The above concerns regarding consistency of listener judgments are evident in every area of communication disorders. As Kent (1996) has noted, the susceptibility of perceptual assessment to a large variety of sources of error and bias poses several threats to the reliability and validity of perceptual measures. The apparent disagreement between perceptual judgments of nasality and instrumental nasalance measures could be the result of inconsistencies associated with perceptual assessment.

As Gerratt and colleagues (1993) noted, professionals in the field of voice quality face a paradox (page 15). That is, clinicians seem to agree on how essential perceptual

judgments are during the clinical decision process as well as in treatment efficacy research, however, because perceptual judgments do not seem precise or reliable enough, clinicians also agree upon the need to supplement perceptual judgments with instrumental analyses. Nonetheless, clinicians still have to use these same questionable perceptual judgments as the standards against which to evaluate instrumental measures. The need for further research is evident.

This study, therefore, focuses on defining the relationship between a perceptual measure and an instrumental measure of hypernasality. It partly addresses the limitations of perceptual auditory judgments of degrees of hypernasality with the use of a cul-de-sac screening test during single word and short phrase repetition. Furthermore, it involves the analyses of acoustic and nasometric speech samples simultaneously recorded from Portuguese speaking Brazilian subjects.

The objective of this investigation is to establish correlation coefficients between nasalance scores (obtained with the Nasometer) and auditory-perceptual judgments of nasality (obtained with group perceptual ratings of presence or absence of hypernasal voice quality). In addition, this investigation also has the aim of determining the Nasometer's sensitivity index (a measure of the instrument's capacity of confirming the presence of hypernasality, in speech samples rated as hypernasal by the listeners); and the Nasometer's specificity index (a measure of the instrument's

capacity of confirming the absence of hypernasality, in speech samples rated as non-hypernasal by the listeners).

CHAPTER 3
METHODS

The purpose of this investigation was to determine the relationship between a perceptual and an instrumental measure of hypernasality. A Pearson Product Moment correlation analysis was used to determine the correlation between a perceptual measure of nasality (established with a cul-de-sac test) and an instrumental measure of nasalance (established with the Nasometer), while predictive analysis was used to establish the Nasometer's sensitivity and specificity indices.

Operational Definition of Terms

The term hypernasal is used in this dissertation in reference to the quality of voice characterized by the presence of excessive nasal resonance during production of oral speech. Perceptual assessment, refers to the screening measure of cul-de-sac testing, while instrumental assessment refers to the use of the technique of nasometry.

Cul-de-sac testing, for this study, involved auditory-perceptual judgments of presence or absence of resonance shifts during paired production of a single word and a short phrase. Each cul-de-sac pair included the repetition of the same speech stimulus, produced once with the nares open and

once with the nares closed. The term resonance shift, therefore, refers to the quality of voice characterized by acoustic input into a closed nasal cul-de-sac resonator. Positive cul-de-sac refers to the perceptual identification of shifts in resonance quality. That is, when judges identified that a pair of stimuli sounded different, that specific pair received a perceptual rating of positive cul-de-sac. Similarly, negative cul-de-sac is used in reference to judges perception of an absence of shifts in resonance quality. That is, when judges perceived that a pair of stimuli sounded the same, that specific pair received a rating of negative cul-de-sac.

Cul-de-sac pairs were rated by a group of 20 judges and a single nasality rating was calculated revealing either the presence or absence of hypernasality. Therefore, when used in this chapter, the term "single nasality rating" refers to the perceptual measure indicative of presence or absence of hypernasal resonance as established by the group of judges.

Instrumental assessment, in this study, involved sound pressure level measurement of each subject's speech signal recorded with the Nasometer during the production of the open nares condition during cul-de-sac test. A nasalance score reflects the ratio of nasal to oral acoustic output energy provided by the Nasometer. Therefore, during this chapter, the term "nasalance score" refers to the instrumental measure reflecting the oral nasal balance of acoustic energy during subjects' production of oral speech stimuli.

The term "suspected velopharyngeal inadequacy" is used in this study to identify the group of patients from the controls (normal speakers, self-reported). That is, subjects presenting with cleft palate and/or palatal fistula were identified throughout this study as suspected VPI cases, while the normal speakers were identified as control cases.

Research Site

The Experimental Phonetics Laboratory (EPL) at the Hospital for Research and Rehabilitation of Cleft Lip and Palate Lesions-University of São Paulo (HPRLLP-USP), at Bauru-SP, Brazil, was chosen as the research site for the recording of the speech samples for this project. The HPRLLP, a branch of the University of São Paulo, is a comprehensive care hospital and rehabilitation center which specializes in the treatment of patients born with craniofacial malformations. The HPRLLP has a current case load of approximately 26,000 patients as it attracts patients throughout Brazil.

The choice of the HPRLLP as the research site for collection of this project's speech samples was not arbitrary. Currently the University of Florida (UF) and the University of São Paulo (USP) are collaborating on a NIH sponsored research project assessing speech outcome after palatal surgery (Williams, 1994). It is expected that data from this study will provide information regarding the

efficacy of the evaluation tools selected for speech assessment for this NIH project.

Finally, data editing, measurement, and analysis of speech samples recorded during this study were performed at the University of Florida Craniofacial Center (UFCFC). The UFCFC and the HPRLLP, are both equipped with a DAT Sony recorder and a Nasometer. The UFCFC also is equipped with a software program "Dr. Speech Science" (Tiger Electronics, 1995), that was used during this study for editing and play-back of perceptual speech samples.

Recorded Subjects

Forty individuals, patients with suspected velopharyngeal inadequacy and staff at HPRLLP, provided the speech samples analyzed in this study (Appendix A). That is, any person, patient or staff who was willing to participate in a 30 minute recording session at the EPL was considered as a potential subject. However, only those individuals who met the following selection criteria when interviewed by this investigator were chosen as subjects for this study:

1. Currently free of presence of upper respiratory infection, congestion or allergies.
2. Willing and able to perform the speech task selected for this study.
3. Able to breathe nasally and capable of humming.
4. Able to produce the nasal word "mamãe" with a shift of resonance during cul-de-sac screening.

All 40 subjects recorded were Brazilian Portuguese speakers, 25 females and 15 males. Twenty seven of those 40 subjects were patients with suspected VPI, with the age ranging from 4 to 54 years, and a mean age of 18 years (Table 4). Thirteen of those 40 subjects were normal speakers with the age ranging from 14 to 42 years, and a mean age of 24. n Even though desirable, age and gender control were not possible during this study as all subjects were not scheduled for recording session having to volunteer time from other scheduled visit at the HPRLLP-USP to participate in the study.

Table 4
Mean Age, Age Range, and Gender of Subjects Recorded During the Study

Subjects	Mean Age	Age Range	Males	Females
VPI	18	4-54	13	14
Controls	24	14-42	2	11

Speech Stimuli

The word "bebê" (baby) and the short-phrase "o bebê babou" (the baby drooled) were used as the speech stimuli. The present investigator considered this speech sample to be achievable for a Brazilian population as young as 4 years of age. Both stimuli are linguistically meaningful samples of the Portuguese language as spoken by Brazilians.

The presence of excessive nasality during production of the speech stimuli was expected to be exaggerated during the nares closed condition of cul-de-sac testing. The phonetic

context of the plosive voiced phoneme /b/, was expected to enhance acoustic difference between the nares open and nares closed condition for individuals with hypernasality. That is, the pressure requirements for the production of the phoneme /b/ was expected to favor displacement of acoustic sound energy into the nasal cul-de-sac resonator of hypernasal speakers.

The use of a single word as stimuli during cul-de-sac testing has been described earlier (pages 10-13). The use of a short phrase was proposed in this study in an attempt to partly overcome the limitations of using only single words for elicitation of speech samples representative of an individual's communicative abilities. Both complexity and length of the phrase were intentionally kept simple and short in attempt to improve recording of non-compliant subjects.

Speech Task

All subjects were required to repeat the stimuli twice: once with their nares open and once with their nares gently pinched closed. The nares open condition provided the baseline information for the cul-de-sac test. The nares closed condition provided the testing condition to be compared against the baseline, characterizing therefore the paired comparison for the cul-de-sac test selected for the perceptual assessment performed in this study.

This investigator predicted that the presence of oral-nasal cavities coupled together during speech production

would create a cul-de-sac resonator when the nares were pinched closed. The displacement of acoustic energy within this cul-de-sac resonator was expected to result in a distinct shift of resonance quality compared to the nares open condition. A shift in resonance quality during the cul-de-sac test was expected, therefore, to be perceptually identified in the speech of individuals lacking velopharyngeal closure or presenting with palatal fistulas.

Instrumentation for Data Recording and Manipulation

During this study a Kay Elemetrics' Nasometer, Model 6200-2, software 3.1, and a Sony Digital Audio Tape Deck, Model DCT-690, were used for recording the speech samples produced by all subjects. Data for perceptual and instrumental analyses were recorded simultaneously for each subject and stored in the computer (instrumental data) and on tape (perceptual data) for later analysis.

The Nasometer

The Nasometer consists of three sub-units: (a) a sound separator unit with two directional microphones placed on the top and bottom of a metal plate (positioned so that one microphone is in front of the nose and the other microphone is in front of the mouth), all of which can be attached to the speaker's head with the use of an adjustable headgear assembly; (b) electronic circuitry for frequency band-limiting and processing of the speech signals picked up by the microphones; and (c) a software program to be utilized

with personal computers, designed to receive, process, display, and store data, and calculate nasalance scores (Fletcher, McCutcheon, & Adams, 1989).

Each microphone in the Nasometer's sound separator unit is connected to its own tunable filter network with identical band widths and frequency ranges. The microphones are capable of processing frequencies between 50 and 20,000 Hz. This system identifies a resonant frequency in the nasal channel and, at the same time, tracks the same frequency band in the oral signal. The acoustic signals are then filtered and digitized by the Nasometer. The resulting "voltage" is processed by a computer, which uses a software program (Version 3.1) produced by Kay Elemetrics (1992).

Data management. The Nasometer's software program allows for automatic data acquisition, data editing, data analyses, stimulus presentation, display generation, and management of data files. This software displays the data in real time on the computer screen, allowing for immediate feedback regarding oral nasal balance of the acoustic output. Data can be saved for editing and measuring at a later time, or the "Calculate Function" of the Nasometer's software program can be used for prompt display of nasalance scores.

The automatic computation of nasalance scores involves dividing the recorded energy of the nasal acoustic signal by the sum of nasal plus oral acoustic signals. The resultant ratio is then multiplied by 100 to be converted to a percentage:

$$\% \text{ Nasalance} = \frac{\text{Nasal Sound Pressure(SPL)}}{\text{Oral SPL + Nasal SPL}} \times (100)$$

Nasometric recording condition. An adaptation of the Nasometer's standard headgear recording condition, described by Dutka (1992), were used in this study. For this adjusted condition the sound separator plate was held by standard laboratory clamps and attached to a metal post rather than held by the headgear harness and attached to the speaker's head. According to Dutka's study, no significant difference was found between nasometric data recorded with the standard headgear and the adapted conditions. It is recognized that consistent contact between separator plate and subject's philtrum[1] is required for the recording of reliable nasometric data.

To help assure stable positioning of subject's philtrum against the separator plate a pressure switch was adapted to the metal plate. The switch activated a small light as long as the subject was in contact with the plate. Neither the switch nor the light interfered with speech production. A second examiner was constantly present during all recordings assisting with subject's placement against the separator plate and switch.

The Digital Audio Tape-Recorder (DAT)

A Sony DAT (model 690), a DBX pre-amplifier (760x), and an Audio Technica unidirectional microphone (ATM73a) were used for recording the acoustic signal to be used in the

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[1] Philtrum refers to the area between the vermilion border in the upper lip and the base of the nose.

perceptual analyses. To allow for simultaneous recording by the DAT and the Nasometer, the DAT microphone was attached (with a standard laboratory clamp) to the same metal post holding the Nasometer's separator plate. With this arrangement the DAT microphone was held, throughout all recordings, at a constant 12 inches mouth to microphone distance.

Recording Procedures

During this study the Nasometer was calibrated twice daily, once before the morning session and again before the afternoon session. Before subjects were positioned against the Nasometer separator plate, the plate was cleaned following manufacturer's instructions. A calibration tone was recorded in each of the DAT tapes allowing for later review of average sound pressure levels of each speaker.

The stand with all three microphones were positioned on a desk with a chair where subjects were comfortably seated. All subjects were instructed to approach the stand, keeping the separator plate in light contact with the philtrum such as using a "pretend mustache". While gently assisting the positioning of each subject in front of the separator plate, the investigator made the necessary adjustments of the stand so that the separator plate was positioned as comfortably as possible in contact with the subject's philtrum during the entire recording section. As soon as subjects' philtrum touched the separator plate the mechanical switch's light

would turn-on. Trials in which the subject moved away from the separator plate and/or the light turned off were repeated.

Subjects instructions/training. The investigator instructed each subject to repeat the speech stimuli twice: first repetition with nares open and second with nares closed by the investigator. Perceptually identified errors such as mispronunciation and omitting sounds, or extreme variations in pitch, loudness, prosody, duration or articulation were deleted from the sample and that segment was recorded again.

Throughout all recording sessions a second investigator was present to help monitor subjects' positioning and to close subjects' nares. Subjects were allowed to practice as many times and as long as necessary for achievement of successful production.

Data management. A computer monitor allowed the investigator to observe the plot for nasometric data while the DAT VU meter allowed for monitoring of the acoustic signal being recorded digitally. A log was kept for the DAT tapes including subjects' ID number and respective counter readings for each stimuli recorded. The nasometric data was stored on the computer hard drive and each sample was identified by a code created with the subjects' ID and an entry number for each stimuli.

Sound pressure level control. Besides being perceptually monitored by the investigator, extreme variations of subjects' vocal loudness during data recording were monitored

by the data display on the computer monitor, as provided with the Nasometer software package. That is, speech signals with an extremely low input were not recorded by the Nasometer, yielding no data display which was confirmed by the perceptual impression of the investigator. Such trials were repeated. On the other hand, speech signals with extremely loud input prompted the Nasometer's "caution light", and such trials also were repeated.

Moreover, to assure that any difference in nasalance scores between subjects were not related to variability loudness of subjects' voice, average sound pressure level for all digitally recorded samples were calculated (CSpeech 4.0, Milenkovic, 1992). A table with average SPL measures for each subjects is presented in Appendix B.

Perceptual Assessment of Recorded Samples

Perceptual Data. The samples recorded with the Sony digital audio tape-recorder were entered into a Pentium PC (Gateway 2000) with the use of the Sound Blaster 16 sound card. The commercially available software program for speech analyses "Dr. Speech for Windows" (Tiger Electronics, Inc., 3.0, 1995) was used for editing the acoustic data. This program allows for playback and editing of the audio waveforms. With the use of software Edit Menu, desired or undesired portions of digitized audiowaves could be bracketed for cutting, copying and pasting of the speech signal displayed at the computer monitor.

With the use of "Dr. Speech Science" software, a computerized recording was created including speech samples recorded from all 40 subjects. The samples were combined in the same random order in which subjects were recorded at HPRLLP. Duration of pauses between stimuli as well as between speakers was kept constant.

The final recording included a total of 196 samples of speech. That is, the recordings from 40 subjects plus 9 (23%) random repetitions were organized in 96 pairs of cul-de-sac tests. Each pair included an open and a closed nares condition. The two pairs for each subject, one with the word and one with the phrase, were finally combined following the same random order with which they were recorded.

A set of instructions (both in Portuguese and English languages) were recorded also using the "Dr. Speech Science" system (Appendix C). The total computerized recording had a duration of 40 to 45 minutes.

Instructions. The set of instructions was designed to briefly prepare the listeners for their task of identifying the presence of a shift/difference in resonance between the first and the second repetitions of each pair of stimuli. Samples of speech with both positive cul-de-sac (presence of resonance shift) and negative cul-de-sac (absence of resonance shift), were included in the instructions. The listeners were told that their task was to compare the second repetition to the first, only regarding identification of shifts in resonance quality. That is, they were told to

disregard, during their judgments, the presence of other identifiable differences such as pitch, intensity, duration, prosody or differences in articulatory production such as use of compensatory articulation (e.g. glottal stops). Samples illustrating these differences were included. However, all listeners only heard the instructions once and practicing trials were not provided.

Listening session. Before rating the samples each listener was provided with a written copy of the instructions which they read while listening to the recorded instructions and samples. Before starting, listeners were informed regarding the need for breaks during the rating session. They were told that, although they would hear each sample only once, a break between subjects could be provided, whenever necessary.

Each listener received a scoring sheet to mark his/her perceptual impressions of the samples they heard (Appendix D). Judges were required to select only one of three choices in rating each pair of stimuli: a) the two productions sounded the same; b) the two productions sounded different; and c) "unsure" if the two productions sounded the same or different.

Listeners. Twenty listeners (2 males and 18 females) rated the recordings once (Appendix E). Eighteen of the listeners were fluent speakers of the Portuguese language, while two spoke English only. All listeners were either speech language pathologists (N = 5) or students (N = 15) in

a speech language pathology program. The age range for the group varied from 20 to 68 years, with a mean of 27. All listeners reported having normal hearing; however, no audiometric assessments were performed.

Data Measurement

Perceptual data.

All ratings of the presence (positive cul-de-sac) or the absence (negative cul-de-sac or "unsure") of resonance shifts were combined in a single score sheet for the word and a single score sheet for the phrase. A total of 1,960 pairs of stimuli were rated by the group of 20 listeners. That is, 49 cul-de-sac pairs for the single word and 49 cul-de-sac pairs for the short phrase were rated 20 times each (49 X 2 X 20 = 1,960).

Interpretation of perceptual ratings of nasality. A single perceptual score was obtained for each of the 40 subjects. That is, a percentage of agreement between all 20 judgments regarding either the presence or the absence of shifts of resonance was obtained for each pair. The following criteria was used for establishing a dichotomous representation of the perceptual data according to either presence or absence of hypernasality:

1. Agreement between 55% or more of the judges towards either the absence or the presence of resonance shifts was used for establishing a nasality single score for each speaker.
2. Nasality ratings of "1" were used to identify those subjects for which 55% or more of the judges (11

or>) identified the presence of resonance shift during cul-de-sac test.

3. Nasality ratings of "0" were used to identify those subjects for which 55% or more of the judges did not identify the presence of resonance shift or were not sure whether or not they heard a shift.

Nasometric data.

Nasometer's software program 6200-2, version 3.1 (Kay Elemetrics, 1992, Pine Brook, NJ) was used during measurement of nasometric data. Stored speech signals from all 40 subjects were retrieved from a personal computer hard drive while using the Nasometer's retrieving commands and subjects' identification codes. With the speech signal displayed on the computer screen the vertical cursors were used for selection of first repetition of each pair (open nares condition). The "calculate" function, within the Nasometer's software program, was used for automatically computing mean nasalance scores for the word and the phrase stimuli recorded for each subject.

Interpretation of nasalance scores. Dichotomous representation of the data was necessary for the estimation of measures of sensitivity and specificity of the Nasometer in confirming respectively presence and absence of hypernasality. A nasalance cut-off score was used to dichotomously divide the group of subjects into sub-groups of normal or hypernasal. The control's group mean nasalance score of 27% during production of the word "bebê" was arbitrarily selected as the nasalance cut-off score for calculation of the Nasometer sensitivity and specificity with

word samples (Appendix F). Similarly, the control's group mean nasalance score of 21% during production of the phrase "o bebê babou" was arbitrarily selected as the nasalance cut-off score for calculation of the Nasometer sensitivity and specificity with phrase samples (Appendix G).

Data Analysis.

Measures of correlation between nasality ratings and nasalance scores were computed according to the Person Product Moment correlational model. The Nasometer's sensitivity and the specificity in confirming respectively presence and absence of hypernasality were determined as described by Feinstein (1977).

CHAPTER 4
RESULTS

This study investigated the relationship between auditory-perceptual and instrumental measures of hypernasality. Listeners' (N=20) perceptual judgments of resonance shift during a cul-de-sac test were used to provide a subjective measure of the presence of hypernasality for 40 subjects. Nasalance scores obtained with a Nasometer were used to provide an objective quantification of nasal to oral acoustic energy. Speech samples were recorded during each subjects' production of the word "bebê" and the phrase "o bebê babou".

Descriptive Data

Results of perceptual and instrumental analyses of speech samples from all 40 subjects during production of both word and phrase are reported below. See Appendix H for tables with raw data.

Perceptual Analyses

As described in the previous chapter, a single nasality rating--indicating either the presence ("1") or the absence ("0") of hypernasality--was established for each subject. Agreement between 55% or more of the judges (11 or >) in either direction (the presence or absence of nasality) was

used as the criteria for selection of a single nasality rating. Perceptual ratings of "0" were arbitrarily given to samples for which 10 judges identified the presence of a resonance shift while 10 did not hear it.

Pearson Product Moment correlational analysis indicated intrajudge agreement of 0.64 ($p<0.001$). Overall interjudge agreement during ratings of all subjects was identified at a level of 0.74.

Nasality ratings during word production. As shown in Table 5, twenty subjects (50%) were identified as hypernasal during cul-de-sac testing with single word, receiving a nasality rating of "1". From this group, one subject was a control and the remaining 19 were patients with suspected VPI. The other 20 subjects (50%) were identified as normal during cul-de-sac testing with single word, receiving a nasality rating of "0". From this group, 12 were control subjects while 8 were patients with suspected VPI.

Nasality ratings during phrase production. As shown in Table 6, nineteen subjects (47.5%) were identified as hypernasal during cul-de-sac testing with single word, thus receiving a nasality rating of "1". All subjects in this group were patients with suspected VPI. The remaining 21 subjects (52.5%) were identified as normal during cul-de-sac testing with single word, receiving a nasality rating of "0". From this group, 12 were control subjects while 9 were patients with suspected VPI.

Table 5
Subjects' Characteristics, Nasality Ratings and Nasalance Scores for the Word Stimuli

	SUBJECTS	AGREEMENT	NASALITY	NASALANCE	AGE	GENDER	CONDITION
	fb62	90%	0	38%	10	m	VPI
2	hs55	75%	0	27%	18	m	VPI
3	wa36	75%	0	20%	4	m	VPI
4	cm26	70%	0	32%	25	f	VPI
5	rd45	70%	0	31%	22	m	VPI
6	mb50	65%	0	50%	20	f	VPI
7	ll51	60%	0	49%	4	f	VPI
8	ds54	50%	0	37%	24	f	VPI
9	js44	90%	1	58%	12	m	VPI
10	lm21	85%	1	46%	24	f	VPI
11	vs27	85%	1	57%	10	m	VPI
12	ra10	80%	1	55%	17	f	VPI
13	dr49	80%	1	51%	13	f	VPI
14	sm45	80%	1	56%	7	m	VPI
15	fr15	80%	1	47%	35	f	VPI
16	ab35	80%	1	47%	33	m	VPI
17	mc12	75%	1	41%	14	f	VPI
18	af11	70%	1	42%	23	m	VPI
19	em23	70%	1	54%	23	f	VPI
20	rm48	70%	1	53%	5	m	VPI
21	mb14	65%	1	48%	25	f	VPI
22	tm08	65%	1	71%	54	f	VPI
23	tt22	65%	1	46%	8	f	VPI
24	da64	60%	1	56%	8	m	VPI
25	iv20	60%	1	50%	15	m	VPI
26	as39	60%	1	66%	21	f	VPI
27	pl32	60%	1	43%	25	m	VPI
1	af42	100%	0	11%	24	f	control
2	vm56	100%	0	30%	28	f	control
3	co66	95%	0	33%	21	f	control
4	rn60	90%	0	15%	14	m	control
5	jd65	85%	0	11%	22	f	control
6	sp46	80%	0	20%	32	f	control
7	jd47	70%	0	31%	22	f	control
8	al52	70%	0	51%	26	f	control
9	jd31	70%	0	20%	21	f	control
10	ee24	55%	0	19%	42	m	control
11	mt53	50%	0	39%	21	f	control
12	cm40	50%	0	36%	22	f	control
13	lb67	90%	1	41%	21	f	control

Table 6
Subjects' Characteristics, Nasality Ratings, and Nasalance Scores for the Phrase Stimuli

	SUBJECTS	AGREEMENT	NASALITY	NASALANCE	AGE	GENDER	CONDITION
1	js44	75%	1	60%	12	m	VPI
2	da64	80%	1	48%	8	m	VPI
3	iv20	70%	1	38%	15	m	VPI
4	fb62	100%	0	39%	10	m	VPI
5	mb14	85%	1	49%	25	f	VPI
6	ra10	90%	1	53%	17	f	VPI
7	hs55	75%	0	29%	18	m	VPI
8	ds54	80%	1	36%	24	f	VPI
9	dr49	70%	1	54%	13	f	VPI
10	rd45	80%	0	26%	22	m	VPI
11	fr15	100%	1	52%	35	f	VPI
12	as39	90%	1	65%	21	f	VPI
13	mc12	80%	1	38%	14	f	VPI
14	ab35	75%	0	55%	33	m	VPI
15	tt22	80%	1	34%	8	f	VPI
16	lm21	85%	1	46%	24	f	VPI
17	ll51	55%	1	53%	4	f	VPI
18	rm48	55%	1	46%	5	m	VPI
19	af11	65%	1	36%	23	m	VPI
20	tm08	55%	1	74%	54	f	VPI
21	em23	65%	1	45%	36	f	VPI
22	mb50	65%	0	51%	20	f	VPI
23	sm45	50%	0	59%	7	m	VPI
24	pl32	50%	0	42%	25	m	VPI
25	cm26	65%	0	25%	25	f	VPI
26	vs27	85%	1	44%	10	m	VPI
27	wa36	75%	0	30%	4	m	VPI
1	jd65	90%	0	14%	22	f	control
2	rn60	75%	0	8%	14	m	control
3	vm56	100%	0	22%	28	f	control
4	jd47	70%	0	22%	22	f	control
5	af42	95%	0	9%	24	f	control
6	jd31	85%	0	12%	21	f	control
7	cm40	65%	1	32%	22	f	control
8	lb67	65%	0	30%	21	f	control
9	co66	65%	0	24%	21	f	control
10	mt53	60%	0	22%	21	f	control
11	al52	50%	0	42%	26	f	control
12	ee24	65%	0	14%	42	m	control
13	sp46	75%	0	19%	32	f	control

Instrumental Analyses

Nasalance scores were obtained for each subject during their production of the single word "bebê" (Table 5), and short phrase "o bebê babou" (Table 6). Table 7 summarizes group mean nasalance scores for all 40 subjects and for sub-groups according to condition (control vs. suspected VPI) and nasality ratings (normal vs. hypernasal).

Table 7
Group Mean Nasalance Scores

Group Mean Nasalance Score	WORD		PHRASE	
All Subjects	41%	N=40	37%	N=40
Controls	27%	N=13	21%	N=13
Patients with suspected VPI	47%	N=26	45%	N=26
Hypernasal (cul-de-sac +)	51%	N=20	48%	N=19
Normal (cul-de-sac -)	30%	N=20	28%	N=21

Nasalance scores during word production. As shown in Table 7, group mean nasalance score of 41% was identified for all 40 subjects during production of the word "bebê". The group mean nasalance score for the 13 controls was 27%. The group mean nasalance score for the sub-group including only the patients with suspected VPI was 47% (N=27).

When only the subjects perceptually identified as hypernasal during cul-de-sac testing (N=20) were considered, the group mean nasalance was 51%. The remaining 20 cases for which perceptual testing indicated normal resonance presented with a group mean nasalance score of 30%.

Nasalance scores during phrase production. As shown in Table 7, a group mean nasalance score of 37% was identified for all 40 subjects during production of the phrase "o bebê babou" was 37%. The group mean nasalance score for the 13 controls was 21%. The group mean nasalance score for the sub-group including only the patients with suspected VPI was 45% (N=27).

When only subjects perceptually identified as hypernasal during cul-de-sac testing were considered, the group mean nasalance was 48% (N=19). Those remaining 21 cases for which perceptual testing indicated normal resonance presented with a group mean nasalance score of 28%.

Measures of Correlation Between Nasality and Nasalance

Subjects' mean nasalance scores were paired to their single nasality ratings for computation of correlation analysis (raw data in Appendix H). All correlation measures presented in Table 8 were calculated with the use of the software program for statistical analysis "Plot50" (Sigma Stat).

Correlation Measures for Word Samples

A Pearson Product Moment correlation analysis combining perceptual and instrumental data for all 40 subjects during production of the word "bebê" revealed a correlation coefficient of 0.73 ($p<0.001$). When the 13 subjects with perceptual ratings of nasality indicating less than 70% agreement between judges were eliminated from the group, the

correlation coefficient between nasality and nasalance for the remaining 27 subjects was 0.80 ($p<0.001$). Finally, when the 30 subjects with perceptual ratings of nasality indicating less than 85% agreement across judges were eliminated from the group, the correlation between nasality and nasalance for the remaining 10 subjects was 0.81 ($p<0.004$).

Table 8
Correlation Between Nasalance and Nasality

Relationship between Nasality and Nasalance	Correlation Coefficients			
Criteria for Perceptual Ratings	WORD		PHRASE	
55% or more agreement among judges	.73	N=40	.61	N=40
70% or more agreement among judges	.80	N=27	.73	N=25
85% or more agreement among judges	.81	N=10	.88	N=10

Correlation Measures for Phrase Samples

A Pearson Product Moment correlation analysis combining perceptual and instrumental data for all 40 subjects during production of the phrase "o bebê babou" revealed a correlation coefficient of 0.61 ($p<0.001$). When the 15 subjects with perceptual ratings of nasality indicating less than 70% agreement between judges were eliminated from the group, the correlation between nasality and nasalance for the remaining 25 subjects was 0.73 ($p<0.001$). Finally, when the 30 subjects with perceptual ratings of nasality indicating less than 85% agreement between judges were eliminated from

the group, the correlation between nasality and nasalance was 0.88 ($p<0.001$).

Measures of Sensitivity and Specificity

The Nasometer sensitivity and specificity in confirming respectively the presence and the absence of hypernasality were computed for both word and phrase productions. As described earlier, the sensitivity of an assessment tool is determined by the number of true positive cases divided by the sum of true positive plus false negatives (Table 9) Specificity, on the other hand, is determined by the number of true negative cases divided by the sum of true negative plus false positive cases (Table 9).

For this study, true positive cases were operationally defined as those subjects identified as hypernasal by both cul-de-sac test and nasometric assessment. True negative cases were defined as those subjects identified as normal by both cul-de-sac test and nasometric assessment. Confirmed positive cases were all subjects identified as hypernasal by nasometric assessment, while confirmed negative were all subjects identified as normal by nasometric assessment.

While dichotomous representation of perceptual data was the criteria for perceptual analyses of subject's speech samples as either hypernasal or normal, nasometric data were not dichotomously represented. Group mean nasalance scores obtained for the 13 control subjects were used as the

nasalance cut-off scores for yielding a dichotomous representation of nasometric data in this study.

Table 9
Measures of Sensitivity and Specificity

Nasalance Scores	Perceptual Ratings HYPERNASAL (cul-de-sac +)	Perceptual Ratings NORMAL (cul-de-sac -)	Total
HYPERNASAL (> cut-off)	true positive cases	false positive cases	confirmed positive cases
NORMAL (< cut-off)	false negative cases	true negative cases	confirmed negative cases
Total	Sensitivity	Specificity	N

Sensitivity and Specificity for Word Samples

Dichotomous representation of the nasometric data obtained during production of the word "bebê" was established with the use of a nasalance cut-off score of 27%. That is, in this study nasalance scores above 27% were interpreted as indicative of the presence of hypernasality. As with the correlation measures, Nasometer test sensitivity and test specificity were initially established for all subjects as a single group (Table 10).

Measures for the entire group of subjects (N=40). As shown in Table 10, all 20 subjects perceptually identified as hypernasal presented with nasalance scores above the cut-off value of 27% (true positive cases). No subject who was perceptually rated as hypernasal presented with a nasalance score below the cut-off value of 27% (no false negative cases). Therefore, the division of true positive cases (20)

by the sum of true positive cases and false negative cases (20+0=20) indicated a sensitivity of 1.00 for the Nasometer while confirming presence of hypernasality during cul-de-sac testing. That is, perceptual ratings of presence of hypernasality during cul-de-sac testing was 100% confirmed with the Nasometer.

Table 10
Measures of Sensitivity and Specificity of Nasometer during Production of Word "bebê" (N = 40)

	PERCEPTUAL RATING		
NASALANCE	HYPERNASAL (cul-de-sac +)	NORMAL (cul-de-sac -)	TOTAL
HYPERNASAL (> 27%)	20	12	32
NORMAL (< 27%)	0	8	8
	20	20	40
	1.00 sensitivity	0.40 specificity	

Similarly, for the 20 subjects perceptually identified as normal during cul-de-sac testing, 8 presented with nasalance scores at or below the cut-off value of 27% (true negative cases). However, 12 subjects perceptually rated as normal presented with nasalance scores above the cut-off value of 27% (false positive cases). Therefore, the division of true negative cases by the sum of true negative cases and false positive cases (8+12=20) yielded a specificity of 0.40 for the Nasometer while confirming absence of hypernasality

during cul-de-sac testing. That is, perceptual ratings of an absence of hypernasality during cul-de-sac testing was only 40% confirmed with the Nasometer.

Measures of sensitivity and specificity for the group of subjects identified as hypernasal or normal with 70% or more agreement among judges (N=27). As shown in Table 11, all 13 subjects perceptually identified as hypernasal (by 70% or more agreement among judges) presented with nasalance scores above the cut-off value of 27% (true positive cases). No subjects perceptually rated as hypernasal presented with nasalance scores at or below the cut-off value of 27% (no false negative cases). Therefore, the division of true positive cases (13) by the sum of true positive cases and false negative cases (13/13+0=1) indicated a sensitivity of 1.00 for the Nasometer while confirming presence of hypernasality during cul-de-sac testing. That is, perceptual ratings of presence of hypernasality during cul-de-sac testing was confirmed 100% of the time with the Nasometer.

Similarly, for the 14 subjects perceptually identified as normal during cul-de-sac testing, 7 presented with nasalance scores at or below the cut-off value of 27% (true negative cases). However, 7 subjects perceptually rated as normal presented with nasalance scores above the cut-off value of 27% (false positive cases). Therefore, the division of true negative cases by the sum of true negative cases and false positive cases (7/7+7=.50) yielded a specificity of 0.50 for the Nasometer while confirming absence of

hypernasality during cul-de-sac testing. That is, perceptual judgments of no hypernasality during cul-de-sac testing were confirmed only 50% of the time with the Nasometer.

Table 11
Measures of Sensitivity and Specificity of Nasometer for the Group of Subjects Perceptually Rated with 70% or Higher Agreement during Production of Word "bebê" (N = 27)

PHRASE	PERCEPTUAL RATING		
NASALANCE	HYPERNASAL (cul-de-sac +)	NORMAL (cul-de-sac -)	TOTAL
HYPERNASAL (> 18%)	13	7	20
NORMAL (< 18%)	0	7	7
	13	14	27
	1.00 sensitivity	0.50 specificity	

<u>Measures of sensitivity and specificity for the group of subjects identified as hypernasal or normal with 85% or more agreement among judges (N=10)</u>. As shown in Table 12, all four subjects perceptually identified as hypernasal (with 85% or more agreement among judges) presented with nasalance scores above the cut-off value of 27% (true positive cases). No subjects perceptually rated as hypernasal presented with nasalance scores below the cut-off value of 27% (no false negative cases). Therefore, the division of true positive cases by the sum of true positive cases and false negative cases (4/4+0=1) indicated a sensitivity of 1.00 for the

Nasometer while confirming presence of hypernasality during cul-de-sac testing. That is, perceptual ratings of presence of hypernasality during cul-de-sac testing was confirmed 100% of the time with the Nasometer.

Table 12
Measures of Sensitivity and Specificity of Nasometer for the Group of Subjects Perceptually Rated with 85% or Higher Agreement during Production of Word "bebê" (N = 10)

	PERCEPTUAL RATING		
NASALANCE	HYPERNASAL (cul-de-sac +)	NORMAL (cul-de-sac -)	TOTAL
HYPERNASAL (> 18%)	4	3	7
NORMAL (< 18%)	0	3	3
	4	6	10
	1.00 sensitivity	0.50 specificity	

Similarly, for the six subjects perceptually identified as normal during cul-de-sac testing, three presented with nasalance scores at or below the cut-off value of 27% (true negative cases). However, three other subjects perceptually rated as normal presented with nasalance scores above the cut-off value of 27% (false positive cases). Therefore, the division of true negative cases by the sum of true negative cases and false positive cases (3/3+3=.50) yielded a specificity of 0.50 for the Nasometer while confirming an absence of hypernasality during cul-de-sac testing. That is,

perceptual ratings of no hypernasality during cul-de-sac testing was confirmed only 50% of the time with the Nasometer.

Sensitivity and specificity for Phrase Samples

Dichotomous representation of the nasometric data obtained during production of the phrase "o bebê babou" was established with the use of a nasalance cut-off score of 21%. That is, in this study, nasalance scores during production of phrase that were above 21% were interpreted as indicative of the presence of hypernasality. As with the correlation measures, Nasometer test sensitivity and test specificity were initially established for all subjects as a single group (Table 13).

Measures for the entire group of subjects (N=40). As shown in Table 13, all 19 subjects perceptually identified as hypernasal presented with nasalance scores above the cut-off value of 21% (true positive cases). No subjects perceptually rated as hypernasal presented with nasalance scores below the cut-off value of 21% (no false negative cases). Therefore, the division of true positive cases by the sum of true positive cases and false negative cases (19+0=19) indicated a sensitivity of 1.00 for the Nasometer while confirming presence of hypernasality during cul-de-sac testing. That is, perceptual ratings of presence of hypernasality during cul-de-sac testing was confirmed 100% of the time with the Nasometer.

Similarly, for the 21 subjects perceptually identified as normal during cul-de-sac testing, six presented with nasalance scores at or below the cut-off value of 21% (true negative cases). However, 15 subjects perceptually rated as normal presented with nasalance scores above the cut-off value of 21% (false positive cases). Therefore, the division of true negative cases by the sum of true negative cases and false positive cases (6/6+15=) yielded a specificity of 0.29 for the Nasometer while confirming absence of hypernasality during cul-de-sac testing. That is, perceptual ratings of an absence of hypernasality during cul-de-sac testing was confirmed only 29% of the time with the Nasometer.

Table 13
<u>Measures of Sensitivity and Specificity of Nasometer during Production of Phrase "o bebê babou" (N = 40)</u>

	PERCEPTUAL RATING		
NASALANCE	HYPERNASAL (cul-de-sac +)	NORMAL (cul-de-sac -)	TOTAL
HYPERNASAL (> 27%)	19	15	34
NORMAL (< 27%)	0	6	6
	19	21	40
	1.00 sensitivity	0.29 specificity	

<u>Measures of sensitivity and specificity for the group of subjects identified as hypernasal or normal with 70% or more agreement among judges (N=27)</u>. As shown in Table 14, all 13

subjects perceptually identified as hypernasal presented with nasalance scores above the cut-off value of 21% (true positive cases). No subjects perceptually rated as hypernasal presented with nasalance scores below the cut-off value of 21% (no false negative cases). Therefore, the division of true positive cases by the sum of true positive cases and false negative cases (13/13+0=1) indicated a sensitivity of 1.00 for the Nasometer while confirming presence of hypernasality during cul-de-sac testing. That is, perceptual ratings of presence of hypernasality during cul-de-sac testing was confirmed 100% of the time with the Nasometer.

Similarly, for the 12 subjects perceptually identified as normal during cul-de-sac testing, five presented with nasalance scores at or below the cut-off value of 21% (true negative cases). However, seven subjects perceptually rated as normal presented with nasalance scores above the cut-off value of 21% (false positive cases). Therefore, the division of true negative cases by the sum of true negative cases and false positive cases (5/5+7=.42) yielded a specificity of 0.42 for the Nasometer while confirming an absence of hypernasality during cul-de-sac testing. That is, perceptual ratings of no hypernasality during cul-de-sac testing was confirmed only 42% of the time with the Nasometer.

Table 14
Measures of Sensitivity and Specificity of Nasometer for the Group of Subjects Perceptually Rated with 70% or Higher Agreement during Production of Phrase "o bebê babou" (N = 25)

	PERCEPTUAL RATING		
NASALANCE	HYPERNASAL (cul-de-sac +)	NORMAL (cul-de-sac -)	TOTAL
HYPERNASAL (> 18%)	13	7	20
NORMAL (< 18%)	0	5	5
	13	12	25
	1.00 sensitivity	0.42 specificity	

Measures of sensitivity and specificity for the group of subjects identified as hypernasal or normal with 85% or more agreement among judges (N=10). As shown in Table 15, all five subjects perceptually identified as hypernasal (with 85% or more agreement among judges) presented with nasalance scores above the cut-off value of 21% (true positive cases). No subjects perceptually rated as hypernasal presented with nasalance scores below the cut-off value of 21% (no false negative cases). Therefore, the division of true positive cases by the sum of true positive cases and false negative cases (5/5+0=1) indicated a sensitivity of 1.00 for the Nasometer while confirming presence of hypernasality during cul-de-sac testing. That is, perceptual ratings of presence

of hypernasality during cul-de-sac testing was confirmed 100% of the time with the Nasometer.

Table 15
Measures of Sensitivity and Specificity of Nasometer for the Group of Subjects Perceptually Rated with 85% or Higher Agreement during Production of phrase "o bebê babou" (N = 10)

	PERCEPTUAL RATING		
NASALANCE	HYPERNASAL (cul-de-sac +)	NORMAL (cul-de-sac -)	TOTAL
HYPERNASAL (> 18%)	5	2	7
NORMAL (< 18%)	0	3	3
	5	5	10
	1.00 sensitivity	0.60 specificity	

Similarly, for the five subjects perceptually identified as normal during cul-de-sac testing, three presented with nasalance scores at or below the cut-off value of 21% (true negative cases). However, other two subjects perceptually rated as normal presented with nasalance scores above the cut-off value of 21% (false positive cases). Therefore, the division of true negative cases by the sum of true negative cases and false positive cases (3/3+2=.60) yielded a specificity of 0.60 for the Nasometer while confirming an absence of hypernasality during cul-de-sac testing. That is, perceptual ratings of no hypernasality during cul-de-sac testing was confirmed 60% of the time with the Nasometer.

Table 16 summarizes sensitivity and specificity measures for production of the word and the phrase, and under the three perceptual agreement criteria.

Table 16
Summary of Sensitivity and Specificity Measures

	All Subjects		70% Criteria		85% Criteria	
	Word (N=40)	Phrase (N=40)	Word (N=27)	Phrase (N=25)	Word (N=10)	Phrase (N=10)
Sensitivity	1.00	1.00	1.00	1.00	1.00	1.00
Specificity	0.40	0.29	0.50	0.42	0.50	0.60

Implications of these findings are discussed in the next chapter. Future research questions are also presented.

CHAPTER 5
DISCUSSION AND CONCLUSION

This study investigated the relationship between perceptual ratings of nasality and instrumental nasalance scores for Portuguese speaking individuals in Brazil. Correlation coefficients were calculated to reveal the level of agreement between the nasalance scores and the listeners' perceptual judgments. Sensitivity and specificity measures were calculated to reveal the efficiency of the Nasometer while confirming the presence or absence of perceptually identified hypernasality.

Correlation Between Nasalance and Nasality

Significant correlations were found between nasality perceptual measures and nasalance instrumental scores showing that the measurements obtained with the instrument predicted auditory perceptual identification of presence or absence of hypernasality 73% of the time during production of the single word "bebê" ($p < 0.001$), and 61% of the time during production of the phrase "o bebê babou" ($p < 0.001$). As identified in chapter two, the strength of the relationship between perceptual ratings of nasality and nasalance scores has varied widely across studies (Table 2, page 35). When compared to the findings reported in the literature the

correlation coefficients established in this study falls near the middle range between the best (.82, Dalston et al., 1991a) and the worst (.49, Watterson et al., 1993). Preliminary interpretation of such findings did not seem to indicate a trend either towards a high correlation or a low correlation between nasality and nasalance. And even though the results of this study seem to indicate that a substantial relationship exists between the perceptual and the instrumental measures, the instrument (Nasometer) nonetheless failed to identify either the presence or the absence of hypernasality in a considerable amount of cases. Accordingly, in the literature, while some authors have reported being "impressed with the extent to which the Nasometer coincides with independent clinical assessments of hypernasal resonance" (Dalston, et al. 1991a, page 187), other authors have suggested that "nasalance is not a good predictor of hypernasality" (Watterson, et al., 1993, page 23). That is, nasalance scores are more likely to reflect perceptual judgments of hypernasality for those speech samples which are obviously normal or obviously hypernasal.

The need for a careful interpretation of nasalance scores seems to be the consensus among those who use the instrument. As Dalston and colleagues (1993, page 288) pointed out the "correspondence between Nasometer output and clinician assessment is not exact" and inherent limitations of the instrument have been suggested by many authors as the cause for the low correlations found between instrumental

measures of nasalance and perceptual judgments of nasality (Watterson et al., 1993 & 1996; Nellis et al., 1992; Paynter et al., 1991). No authors, however, seem to consider the possible limitations in the perceptual judgments used as the standard comparators for establishment of the measures of agreement between nasalance and nasality. The development of instrumentation leading to objective and valid measurement of physiologic and acoustic correlates of speech has been proposed as means to improve diagnostic and therapeutic efficacy due to its "significant advantages over unaided perceptual judgments" (Baken, 1987). As Baken discusses, instrumental advantages include:

> 1) Increased precision of diagnosis, with more valid specification of abnormal functions that require modification; 2) More positive identification and documentation of therapeutic efficacy, both for short term assessment (is a given approach modifying the abnormal function?) and long term monitoring (how much has speech behavior changed since the inception of therapy?); 3) Expansion of options for therapy modalities. Most measurement techniques offer a means of demonstrating to the patient exactly what is wrong, and they can usually provide feedback on the degree of his success in modifying the fault. (1987, page 2)

Notwithstanding the fact, however, that instrumental measures have been strongly advocated as being more objective and replicable than listeners judgments, still any instrument to be used in speech measurement needs to be validated against those same perceptual judgments of speech usually described as less valid or imprecise. Therefore, the paradox that clinicians and researcher have long faced in the development of measures for determining in a quantitative manner the physiologic and acoustic characteristics for

perceptually identified qualities of the speech signal is not different from the paradox faced by the author of this dissertation. Further examination of the correlational data established in this study revealed that measures of relationship between nasalance and nasality increased linearly as the criteria for listeners' judgment agreement increased. That is, when correlational measures were calculated only for the speech samples rated with 70% or greater listeners' agreement, and later recalculated only for those with 85% or greater agreement, correlation coefficients increased suggesting that the higher the overall interjudge agreement the better the relationship between instrumental and perceptual measures.

Establishment of the usefulness of nasalance scores in correctly predicting hypernasality seems to be related not only to the instrument properties/limitations as described in literature, but also to the consistency in the use of the perceptual tool providing the standard measure against which the instrument is validated. In the previous studies investigating relationship between instrumental measures of nasalance and perceptual measures of nasality, the lack of standardization of perceptual tools and limited control over judges' reliability could have been the main source for such a large variation in the relationship measures reported. Nonetheless, none of the previous studies have addressed this issue of possible limitations of their perceptual data. That is not to say, however, that authors are not aware that

errors and variations in the perception of speech can be numerous, and more specifically, that the problems with perceptual assessment of speech appear to be applicable to a wide range of communication disorders. In fact it is this issue that appeared to have driven so many researchers into a search for a fixed set of acoustic measures that correlate highly to perceived severity of speech abnormalities.

On the other hand, this same concept of perceptual acoustic correlates, as discussed by Kent (1996, page 18), could to be "a helpful guide in establishing perceptual-acoustic validation". Improvement of auditory perceptual assessment (validity and reliability of the measure), therefore, seems critical not only to improve correlation between instrumental and perceptual measures but also to assure quality of clinical action. As Kent indicated, the use of reference samples of voice/speech, listeners' training sessions, together with the acknowledgment of failings and limitations associated with auditory perceptual assessment could be some of the measures for correcting/minimizing shortcomings of auditory perceptual judgments. Associating such measures, continues Kent, with a gradual growth of normative database for a wider ranges of speakers and an improved interpretation of acoustic data could lead to a more efficient combination of perceptual and instrumental methods.

Acoustic Correlates of Nasality

The search for acoustic correlates of perceived nasality has been extensive. The findings, however, have been limited and inconsistent. While discussing the reasons for the inconsistencies reported in the results of nasalization studies, Counihan (1979), reported that

> a primary difficulty in experiments that have searched for acoustic correlates of nasality is the problem of defining nasality. This problem is not merely defining in an individual experiment what a given group of judges will agree to call nasality but one of establishing a common set of criteria that will enable investigators to differentiate this quality from other voice qualities that are present within a given sample. The real possibility that the nasality construct embraces a variety of disparate quality disturbances is one that needs to be carefully investigated. More refined perceptual measures may need to be evolved before definitive relationship between acoustic and perceptual dimensions can be derived. (page 282)

During his discussion Counihan also suggested that the term nasality appears to have no validity and therefore hinders attempts to identify objective indices of subjectively perceived nasality. Baken (1987) further explains the problem reporting that

> the basic flaw in earlier research is the assumption that the nasal space represents one more fixed resonator that adds its own particular contribution to the combined acoustic properties of the other relatively independent resonators making up the vocal tract. In other words, the difficulty lies in the assumption of a separate "nasal resonance" added to other separate resonances. Dunn (1950) has presented a model of the vocal tract that has been shown to be more explanatory of speech acoustics. According to his construct, the vocal tract can be said to consist of a set of cylinders arranged in series. Each of these, in some sense, has acoustic properties but, because the cylinders are connected in a string, they are enormously interdependent. None makes an identifiable isolated

> contribution to the final acoustic product. Quite contrary: the contribution of any given region of the vocal tract is very much a function of all of the other regions. The final result is very different from the simple sum of a set of independent parts. Consequently, coupling of the nasal cavity to the rest of the system does not add an invariant resonator, but rather it just changes the overall nature of a complex acoustic system. The resonance characteristic of the nasal cavity interact with the variations in vocal tract shaping required for different vowels. Therefore, different vowels have different acoustic "nasalization" characteristics. Similarly, individual variations in vocal tract anatomy lead to differences in acoustic correlates of nasality from one speaker to another. (page 400)

Solving the problem of finding acoustic correlates of speech nasality does not seems simple, and much less so when the dynamics of speech production and the interactions within the speech system are taken into consideration. The fact that the majority of studies report only weak associations between acoustic measures and listeners perceptual ratings seems to confirm such a picture. Daniloff and colleagues (1980) have stated that "the purpose of vocal tract movement is to control airflow simultaneously with changing the shape of the vocal tract so that a stream of sound is created. The control of airflow is an aerodynamic purpose; the control of shape is an acoustic purpose . . . it means that the intent to speak implies making sounds, and the positions and movements of articulators are not an end in themselves but the means of making sounds" (page 297). While listeners, therefore, seems to focus on the end-product, instruments seem to deal with the process. That is, by measuring specific parameters of the speech signal, instruments respond to either acoustic or aerodynamic characteristics which are

not readily available to listeners failing to "perceive" the ones that listeners seems to attend to. Listeners ratings and instrumental measures, therefore, appears to supplement one another and, therefore, one can not be used as a substitute for the other. Perceptual and instrumental measures, therefore, are both highly susceptible to threats of validity and reliability whether used alone or in combination. And it is likely that the variance in measures of relationship between perceptual ratings of nasality and nasalance scores could be reflecting the presence of either perceptual or instrumental biases or errors.

Nasometer Sensitivity and Specificity

Notwithstanding the lack of evidence supporting a strong positive relationship between perceptual measures of nasality and nasalance scores, nasometry is rapidly gaining broad clinical acceptance as a routine procedure in assessment protocols of craniofacial centers around the world. Measures of sensitivity and specificity of the instrument, while confirming clinicians' subjective impressions, seems to have dictated the instrument acceptability in the clinical arena (Table 3, page 36).

Dalston and colleagues (1993), for example, reported that "correlation analysis may not be the most appropriate technique for determining the value of nasometry for assessing the oral-nasal balance of patients seen at craniofacial centers . . . the prediction analyses appeared

to be more useful in determining the clinical utility of the Nasometer" (page 288). In agreement to Dalston and colleagues many authors have reported indices of sensitivity and specificity of the Nasometer to describe the usefulness of nasalance scores as predictors of hypernasality (Dalston et al., 1991a; Hardin et al., 1992; Paynter et al., 1991; Stellzig et al., 1994; Watterson et al., 1993 & 1996).

Clinical usefulness of prediction analysis in nasometry requires the establishment of threshold values (cut-off scores) for the interpretation of nasalance scores as indicative either of the presence of an acceptable amount of speech nasality or the presence of a pathological amount of nasality. As observed in the literature different clinicians select different threshold values in an effort to better dichotomize their data for prediction analyses (Dalston et al. 1991a; Dalston et al., 1993; Paynter et al., 1991; Hardin et al., 1992; Watterson et al., 1993 & 1996). However, as Dalston and colleagues (1993) have stated:

> it is important to note that the establishment of a threshold value in a prediction analysis should not be interpreted to mean that clinicians should use threshold values in their evaluation of patients . . . that value should never be considered a rigid instrumental indicator of which patients do or do not require physical management . . . it seems appropriate to suggest that clinicians should think in terms of ranges when interpreting a patient's nasalance score . . . [and] if such an interpretation agrees with an experienced clinician's perceptual assessment of the patients, then the clinician may feel justified in making clinical recommendations based upon that information. (page 289)

In the present study group mean nasalance scores obtained for the control speakers were selected as cut-off

values. With these choices of cut-off values to calculate the Nasometer test sensitivity and specificity, the possibility of the instrument missing hypernasal speakers was minimized while the possibility of "over-rating" normal speakers as hypernasal was maximized. While many investigators have justified their arbitrary selection of an "optimum nasalance cut-off value", as the best choice for assessing the instrument's overall efficiency, this investigator believes that the purpose of serving a clinical population justifies the use of a more conservative approach.

With the nasalance cut-off score of 27% for the word and 21% for the phrase, the Nasometer sensitivity was established at level 1.00 for both word and phrase, while specificity reached only 0.40 for the word and 0.29 for the phrase. That is, while no subject was "misclassified" as normal when presenting hypernasal speech, 12 subjects were "misclassified" as hypernasal while presenting normal speech during word production, and 15 subjects were "misclassified" as hypernasal while presenting normal speech during phrase production.

Sensitivity and specificity measures established in this study reflect good instrument sensitivity in confirming perceptually identified hypernasal speech. This finding can be interpreted as evidence of the presence of a linear relationship between nasal displacement of sound pressure energy and distinction of resonance shift. That is, the greater the amount of sound energy within the nasal cavity

the better the agreement among judges regarding the perception of resonance shifts during cul-de-sac tests (as predicted by this investigator). The specificity measures, on the other hand, were quite low as determined by the choice of the conservative cut-off score based on the mean score from the control rather than using the score that could best dichotomize the data. Independently of the choice of cut-off score, further observation of the data indicated that predictive measures also increased linearly as criteria for listeners' judgment increased.

Conclusion

The relationship between a perceptual measure of hypernasality (during use of cul-de-sac test) and an instrumental measure of hypernasality (obtained with the Nasometer) was established in this study. Both, correlation coefficients and indices of sensitivity and specificity, increased linearly with the level of agreement among the judges rating the speech samples. This finding points towards a trend for a better relationship between perceptual ratings of nasality and nasalance scores for those speech samples perceptually rated with high listeners' agreement. This information seems to magnify a long recognized problem: that perceptual tools need further refinement. In addition, there seems to be a call for a new direction while interpreting the results of studies reporting poor relationships between the variables of nasality and

nasalance. Perceptual assessment has been taken for granted in all of these studies, including those reporting intra- and inter-judge reliability. And as Kent (1996) stated:

> it can not be taken for granted that any given term used in perceptual assessment will have the same meaning for any two judges, or that two judges will share a verbal description of a clinical speech sample. (page 16)

The lack of agreement between nasalance scores obtained with the Nasometer and listeners perceptual judgments reported in many studies (Nellis et al., 1992; Hardin et al., 1992; Paynter et al, 1991; Watterson et al. 1993; Watterson et al., 1996) may be related primarily to limitations of auditory-perceptual ratings. Unless researchers assure that listeners <u>at least</u> use an equivalent definition of nasality and are prepared to isolate this single perceptual dimension of speech from all other co-occurring dimensions (e.g. pitch, intensity, prosody, articulation, duration), we should be cautious in our conclusions regarding the findings of any relationship.

Establishment of clinical confidence in nasalance measures as predictors of perceptual measures of nasality, certainly depends on the determination of the usefulness of the instrument while confirming clinical impressions. The use of measures of relationship, such as correlation coefficient, as indicators of the usefulness of the Nasometer, however, seems to require further control over perceptual judgment of the speech samples selected as standard measures. While it seems logical that no one would disagree with Baken's statement that "there is no instrument,

no technique, no computer that can begin to match the human auditory system for detecting subtle acoustic variations or for determining whether they represent varieties of normal or nonnormal speech" (page 1), the use of perceptual judgments, as Kent has described (1996), "is not always taught with an appropriate emphasis on their limitations or the selection of alternative methods if certain assumptions are not satisfied" (page 16). Development of standard procedures for both, perceptual ratings and listener training, might contribute towards a more effective and refined use of perceptual tools.

Inherent Limitation of the Instrument

Some facts can not be changed even when perceptual tools are refined. Instrumental nasalance scores are conceptually different from listeners auditory-perceptual ratings. That is, while the Nasometer involves measures of a single dimension of the speech signal (sound pressure level), auditory-perceptual ratings are influenced by many co-occurring dimensions of speech. Even a "perfect" correlation, therefore, could not justify using nasalance scores as the standard instead of auditory-perceptual ratings. Nasalance scores combine the presence of hypernasality to a numerical value which appear to be a good predictor of sound pressure energy displacement into the nasal cavity. However, it seems reasonably to suggest that nasalance scores can be used as predictors of the presence of VPI only when nasality is operationally defined and standardly described/demonstrated to listeners as a distinct

perceptual attribute associated to nasalization (coupled oral/nasal cavities).

Limitation of this Study

Even though, during this study, all listeners were provided with a brief instructional section which cautioned the possibility of co-occurring changes in more than one speech dimension, a practice session was not provided and test samples were not repeated. The rather low overall score of .64 for intrajudge reliability could reflect the need for additional training before proceeding with such a perceptual task.

In an overall the findings of this study revealed the need for further investigation. Recognizing, however, the need for accounting for failing and limitations of both, perceptual and instrumental tools, seems to be an essential step towards answering the following and any other research questions.

Future Research Questions

1. How predictive of individuals' conversational speech quality are measures of hypernasality obtained with cul-de-sac testing?

2. Can cul-de-sac testing be used as "bridges" during listeners' training in order to improve reliability in numerical scaling?

3. Can practice sessions improve listeners' agreement?

4. Can multiple rating trials of cul-de-sac pairs improve listeners' agreement?

5. To further define the distribution of nasalance scores and cul-de-sac ratings during production of word "bebê" and phrase "o bebê babou", for a representative sample of both normal and disordered populations?

6. How predictive of perceptual rating are nasalance scores when representative samples of both normal and disordered populations are used?

APPENDIX
RAW DATA AND DATA SUMMARY

LIST OF ALL SUBJECTS RECORDED

ID	CONDITION	AGE	GENDER	ID	CONDITION	AGE	GENDER
1	normal	21	f	14	suspected VPI	23	f
2	normal	21	f	15	suspected VPI	24	f
3	normal	22	f	16	suspected VPI	8	m
4	normal	21	f	17	suspected VPI	15	m
5	normal	26	f	18	suspected VPI	25	f
6	normal	14	m	19	suspected VPI	21	f
7	normal	21	f	20	suspected VPI	54	f
8	normal	28	f	21	suspected VPI	25	m
9	normal	24	f	22	suspected VPI	8	f
10	normal	22	f	23	suspected VPI	24	f
11	normal	42	m	24	suspected VPI	17	f
12	normal	22	f	25	suspected VPI	4	f
13	normal	32	f	26	suspected VPI	20	f
				27	suspected VPI	12	m
				28	suspected VPI	10	m
				29	suspected VPI	25	f
				30	suspected VPI	10	m
				31	suspected VPI	4	m
				32	suspected VPI	18	m
				33	suspected VPI	13	f
				34	suspected VPI	5	m
				35	suspected VPI	7	m
				36	suspected VPI	22	m
				37	suspected VPI	35	f
				38	suspected VPI	14	f
				39	suspected VPI	23	m
				40	suspected VPI	33	m

SUBJECTS' AVERAGE SOUND PRESSURE LEVELS DURING PRODUCTION OF WORD AND PHRASE STIMULI

	WORD	PHRASE
1	71.13	70.68
2	71.06	70.70
3	71.12	70.68
4	71.10	70.97
5	71.34	70.67
6	71.06	70.91
7	71.06	70.54
8	69.99	70.67
9	71.40	69.61
10	71.21	70.62
11	70.71	70.56
12	70.72	70.55
13	71.18	70.40
14	71.16	70.52
15	70.85	70.77
16	70.77	70.79
17	70.75	70.73
18	70.15	70.32
19	70.76	70.73
20	70.72	70.48
21	70.71	70.30
22	70.68	70.48
23	65.23	70.30
24	71.14	70.48
25	71.08	70.39
26	71.15	70.37
27	71.18	70.85
28	71.95	71.03
29	67.24	71.09
30	71.03	70.88
31	71.11	70.47
32	71.03	70.88
33	71.82	71.14
34	71.18	70.92
35	69.76	70.57

	WORD	PHRASE
36	71.06	70.79
37	69.05	67.83
38	68.45	70.59
39	67.32	71.06
40	71.48	70.52

SUBJECTS' INSTRUCTIONS IN ENGLISH

Name's Initials: Age: Today's date:
Occupation: For how long: Hearing Problems:
Do you know what hypernasality is?
Have you ever heared hypernasal speaker:

In this task you will hear a number of individuals producing twice a list of 4 words, 1 phrase and the sustained vowel /i/. The language spoken is Brazilian Portuguese, and you are not required to understand the meaning of the speech samples. Each speaker will say:

piupiu - piupiu
bebe - bebe
lala - lala
kaka - kaka
o bebe babou - o bebe babou
/iii/ - /iii/

As you just heard, each of the 4 words, the phrase, and the sustained vowel /i/ will be repeated twice in pairs. Your task, for each pair, will be to compare the first repetition to the second, relative to any change in speech resonance. More specifically, you should listen only for a resonance change relative to a shift in nasality such as:

piupiu - piupiu
bebe - bebe
lala - lala
kaka - kaka
o bebe babou - o bebe babou
/iii/ - /iii/

Mark your ratings on the score sheet. For each pair of words you are to select <u>only one</u> of three choices. Your choices are:

(   ) the two productions sounded the SAME
(   ) the two productions sounded DIFFERENT
(   ) NOT SURE if the two productions were the same or NOT

Do not compare the two productions, within each pair, relative to such possible changes as intensity, pitch, articulation, duration or prosody of each production. That is, disregard any variation across the paired productions that are not related to nasality. The following examples reflect changes in pitch, articulation, prosody, intensity, and duration but with no change in nasality:

lala - lala (change in pitch)
kaka - kaka (change in articulation)

o bebe babou - o bebe babou	(change in prosody)
lala - lala	(change in intensity)
/iii/ - /iii/	(change in duration)

It is likely, of course, that a speaker will make a change in his/her production across the two words, for example in pitch or prosody, as well as producing a change in nasality. In this case you would note detecting the difference in nasality.

For some of the paired productions you may find it difficult to easily determine the sameness or difference relative to speech nasality. If you can not readily identify whether the two productions sounded the same or sounded different, do not guess - mark the column (   ) not sure.

OK, let's begin with subject 1!!!

SUBJECTS' INSTRUCTIONS IN PORTUGUESE

Iniciais: Idade: Data:
Ocupação: Por quanto tempo: Problemas Auditivos:
Sabe o que é hypernasalidade?
Já escutou um falante hypernasal?:

A seguir você escutará a gravação de vários sujeitos produzindo uma amostra de fala que inclui: 4 palavras, 1 uma frase e a vogal /i/ prolongada. A língua falada é o Portugues Brasileiro, no entanto, durante esta atividade você não precisa reconhecer o significado da amostra. Cada falante produzirá a seguinte amostra:

piupiu - piupiu
bebê - bebê
Lalá - Lalá
Cacá - Cacá
o bebê babou - o bebê babou
/iiiiiiii/ - /iiiiiiii/

Conforme pudemos perceber, cada uma das 4 palavras, 1 frase e vogal /i/ serão repetidas duas vezes, em pares. Sua tarefa, para cada par, será a de comparar a primeira repetição com a segunda repetição, com relação `a presença de diferenças quanto `a ressonância da fala. Mais especificamente, sua tarefa será a de identificar presença de uma diferença perceptível de nasalidade entre a primeira e a segunda repetição para cada par da amostra como, por exemplo, é possível observar nas seguintes repetições :

piupiu - piupiu
bebê - bebê
Lalá - Lalá
Cacá - Cacá
o bebê babou - o bebê babou
/iiiiiiii/ - /iiiiiiii/

Você ouvirá 50 sujeitos repetindo esta amostra de fala. Depois de ouvir cada par da amostra você deverá julgar (rapidamente) se a primeira repetição foi igual ou diferente da segunda somente com relação ao aspecto de nasalidade. Marque com um X o resultado, sendo para cada par você terá três opções:

( ) NÃO percebi/ouvi diferença quanto `a nasalidade
( ) SIM percebi diferença quanto `a nasalidade
( ) Não pude determinar se existe ou não uma differença

Você deverá fazer o seu julgamento somente quanto `a diferenças da nasalidade, desc onsiderando as possíveis diferenças quanto `a aspectos como intensidade, pitch, entonação, articulação e duração de cada repetição. Isto é,

para cada par analisado não considere variações que não sejam relacionadas `a nasalidade. Por exemplo, os seguintes pares refletem diferenças em pitch, articulação, entonação, intensidade e duração, no entanto, não refletem diferenças em nasalidade:

lala - lala	(pitch)
kaka - kaka	(articulação)
o bebe babou - o bebe babou	(entonação)
lala - lala	(intensidade)
/iii/ - /iii/	(duração)

Portanto para cada par desta amostra o resultado da sua análise deveria ser o seguinte:

(X) NÃO percebi/ouvi diferença quanto `a nasalidade
(   ) SIM percebi diferença quanto `a nasalidade
(   ) Não pude determinar se existe ou não uma differença

É provável, no entanto que você encontre pares nos quais a diferença em nasalidade esteja associada `a diferenças quanto `a intensidade, pitch, articulação, entonação ou duração. Nestes casos, você deveria selecionar a opção: "(X) Sim percebi a diferença de nasalidade".

Caso você encontre pares nos quais não consiga determinar se existe ou não uma diferença marque a opção: "(X) Não pude determinar se existe ou não uma differença". Não "chute!!"

Para analisar a amostra completa (50 sujeitos) levaremos em torno de 45 minutos. Você ouvirá cada par da amostra apenas uma vez e terá que fazer sua análise rapidamente antes que o próximo par seja apresentado. Caso não tenham perguntas começaremos com o primeiro sujeito.

SAMPLE OF SCORING SHEET IN ENGLISH

01

Sample	YES, sounded alike	NO, sounded different	Can not judge
bebe			
o bebe babou			

02

Sample	YES, sounded the same	NO, sounded different	Can not judge
bebe			
o bebe babou			

03

Sample	YES, sounded the same	NO, sounded different	Can not judge
bebe			
o bebe babou			

04

Sample	YES, sounded the same	NO, sounded different	Can not judge
bebe			
o bebe babou			

SAMPLE OF SCORING SHEET IN PORTUGUESE

01

Amostra	NÃO percebi diferença	SIM percebi diferença	Não tenho certeza
bebe			
o bebe babou			

02

Amostra	NÃO percebi diferença	SIM percebi diferença	Não tenho certeza
bebe			
o bebe babou			

03

Amostra	NÃO percebi diferença	SIM percebi diferença	Não tenho certeza
bebe			
o bebe babou			

04

Amostra	NÃO percebi diferença	SIM percebi diferença	Não tenho certeza
bebe			
o bebe babou			

SUMMARY OF LISTENERS' CHARACTERISTICS

ID	OCCUPATION	GENDER	LANGUAGE	AGE
1	student	female	Portuguese	22
2	student	female	Portuguese	22
3	student	female	Portuguese	22
4	student	female	Portuguese	21
5	student	female	Portuguese	21
6	student	female	Portuguese	22
7	student	female	Portuguese	22
8	student	female	Portuguese	22
9	student	female	Portuguese	20
10	student	female	Portuguese	21
11	student	female	Portuguese	22
12	professional	female	Portuguese	31
13	student	female	Portuguese	21
14	student	female	Portuguese	22
15	professional	female	Portuguese	35
16	student	female	Portuguese	20
17	student	female	Portuguese	20
18	professional	male	English	68
19	professional	female	Portuguese	31
20	professional	male	English	57
			mean age	27
			age range	20-68

LEVELS OF AGREEMENT DURING PERCEPTUAL RATINGS, NASALITY RATINGS, AND NASALANCE SCORES FOR SINGLE WORD SPEECH SAMPLES RECORDED FROM THE GROUP OF CONTROLS/NORMAL SUBJECTS

	SUBJECTS	AGREEMENT	NASALITY	NASALANCE	AGE	SEX	CONDITION
1	af42	100%	0	11%	24	f	control
2	vm56	100%	0	30%	28	f	control
3	co66	95%	0	33%	21	f	control
4	rn60	90%	0	15%	14	m	control
5	jd65	85%	0	11%	22	f	control
6	sp46	80%	0	20%	32	f	control
7	jd47	70%	0	31%	22	f	control
8	al52	70%	0	51%	26	f	control
9	jd31	70%	0	20%	21	f	control
10	ee24	55%	0	19%	42	m	control
11	mt53	50%	0	39%	21	f	control
12	cm40	50%	0	36%	22	f	control
13	lb67	90%	1	41%	21	f	control
	MEAN	77%		27%	24		
	SD	18%		12%	7		

LEVELS OF AGREEMENT DURING PERCEPTUAL RATINGS, NASALITY RATINGS, AND NASALANCE SCORES FOR SHORT PHRASE SPEECH SAMPLES RECORDED FROM THE GROUP OF CONTROLS/NORMAL SUBJECTS

	SUBJECTS	AGREEMENT	NASALITY	NASALANCE	AGE	SEX	CONDITION
1	jd65	90%	0	14%	22	f	normal
2	rn60	75%	0	8%	14	m	normal
3	vm56	100%	0	22%	28	f	normal
4	jd47	70%	0	22%	22	f	normal
5	af42	95%	0	9%	24	f	normal
6	jd31	85%	0	12%	21	f	normal
7	cm40	65%	1	32%	22	f	normal
8	lb67	65%	0	30%	21	f	normal
9	co66	65%	0	24%	21	f	normal
10	mt53	60%	0	22%	21	f	normal
11	al52	50%	0	42%	26	f	normal
12	ee24	65%	0	14%	42	m	normal
13	sp46	75%	0	19%	32	f	normal
	MEAN	74%		21%	24		
	SD	15		10	7		

DATA FROM ALL SUBJECTS WITH SUSPECTED VPI
DURING WORD PRODUCTION

	SUBJECTS	AGREEMENT	NASALITY	NASALANCE	AGE	SEX	CONDITION
1	fb62	90%	0	38%	10	m	VPI
2	hs55	75%	0	27%	18	m	VPI
3	wa36	75%	0	20%	4	m	VPI
4	cm26	70%	0	32%	25	f	VPI
5	rd45	70%	0	31%	22	m	VPI
6	mb50	65%	0	50%	20	f	VPI
7	ll51	60%	0	49%	4	f	VPI
8	ds54	50%	0	37%	24	f	VPI
9	js44	90%	1	58%	12	m	VPI
10	lm21	85%	1	46%	24	f	VPI
11	vs27	85%	1	57%	10	m	VPI
12	ra10	80%	1	55%	17	f	VPI
13	dr49	80%	1	51%	13	f	VPI
14	sm45	80%	1	56%	7	m	VPI
15	fr15	80%	1	47%	35	f	VPI
16	ab35	80%	1	47%	33	m	VPI
17	mc12	75%	1	41%	14	f	VPI
18	af11	70%	1	42%	23	m	VPI
19	em23	70%	1	54%	23	f	VPI
20	rm48	70%	1	53%	5	m	VPI
21	mb14	65%	1	48%	25	f	VPI
22	tm08	65%	1	71%	54	f	VPI
23	tt22	65%	1	46%	8	f	VPI
24	da64	60%	1	56%	8	m	VPI
25	iv20	60%	1	50%	15	m	VPI
26	as39	60%	1	66%	21	f	VPI
27	pl32	60%	1	43%	25	m	VPI
	MEAN	72%		47%	18		
	SD	10%		11%	11		

DATA FROM ALL SAMPLES WITH NORMAL PERCEPTUAL RATINGS DURING WORD PRODUCTION

	SUBJECTS	AGREEMENT	NASALITY	NASALANCE	AGE	SEX	CONDITION
1	af42	100%	0	11%	24	f	control
2	vm56	100%	0	30%	28	f	control
3	co66	95%	0	33%	21	f	control
4	fb62	90%	0	38%	10	m	VPI
5	rn60	90%	0	15%	14	m	control
6	jd65	85%	0	11%	22	f	control
7	sp46	80%	0	20%	32	f	control
8	hs55	75%	0	27%	18	m	VPI
9	wa36	75%	0	20%	4	m	VPI
10	cm26	70%	0	32%	25	f	VPI
11	jd47	70%	0	31%	22	f	control
12	al52	70%	0	51%	26	f	control
13	rd45	70%	0	31%	22	m	VPI
14	jd31	70%	0	20%	21	f	control
15	mb50	65%	0	50%	20	f	VPI
16	ll51	60%	0	49%	4	f	VPI
17	ee24	55%	0	19%	42	m	control
18	ds54	50%	0	37%	24	f	VPI
19	mt53	50%	0	39%	21	f	control
20	cm40	50%	0	36%	22	f	control
	MEAN	74%		30%	21		
	SD	16%		12%	9		

DATA FROM ALL SAMPLES WITH HYPERNASAL PERCEPTUAL RATINGS DURING WORD PRODUCTION

SUBJECTS	AGREEMENT	NASALITY	NASALANCE	AGE	SEX	CONDITION
1 lb67	90%	1	41%	21	f	control
2 js44	90%	1	58%	12	m	VPI
3 lm21	85%	1	46%	24	f	VPI
4 vs27	85%	1	57%	10	m	VPI
5 ra10	80%	1	55%	17	f	VPI
6 dr49	80%	1	51%	13	f	VPI
7 sm45	80%	1	56%	7	m	VPI
8 fr15	80%	1	47%	35	f	VPI
9 ab35	80%	1	47%	33	m	VPI
10 mc12	75%	1	41%	14	f	VPI
11 af11	70%	1	42%	23	m	VPI
12 em23	70%	1	54%	23	f	VPI
13 rm48	70%	1	53%	5	m	VPI
14 mb14	65%	1	48%	25	f	VPI
15 tm08	65%	1	71%	54	f	VPI
16 tt22	65%	1	46%	8	f	VPI
17 da64	60%	1	56%	8	m	VPI
18 iv20	60%	1	50%	15	m	VPI
19 as39	60%	1	66%	21	f	VPI
20 pl32	60%	1	43%	25	m	VPI
MEAN	74%		51%	20		
SD	10%		8%	12		

DATA FROM ALL SAMPLES RATED WITH 70% OR MORE LISTENERS' AGREEMENT DURING WORD PRODUCTION

SUBJECTS	AGREEMENT	NASALITY	NASALANCE	AGE	SEX	CONDITION
1 af42	100%	0	11%	24	f	control
2 vm56	100%	0	30%	28	f	control
3 co66	95%	0	33%	21	f	control
4 fb62	90%	0	38%	10	m	VPI
5 rn60	90%	0	15%	14	m	control
6 jd65	85%	0	11%	22	f	control
7 sp46	80%	0	20%	32	f	control
8 hs55	75%	0	27%	18	m	VPI
9 wa36	75%	0	20%	4	m	VPI
10 cm26	70%	0	32%	25	f	VPI
11 jd47	70%	0	31%	22	f	control
12 al52	70%	0	51%	26	f	control
13 rd45	70%	0	31%	22	m	VPI
14 jd31	70%	0	20%	21	f	control
1 lb67	90%	1	41%	21	f	control
2 js44	90%	1	58%	12	m	VPI
3 lm21	85%	1	46%	24	f	VPI
4 vs27	85%	1	57%	10	m	VPI
5 ra10	80%	1	55%	17	f	VPI
6 dr49	80%	1	51%	13	f	VPI
7 sm45	80%	1	56%	7	m	VPI
8 fr15	80%	1	47%	35	f	VPI
9 ab35	80%	1	47%	33	m	VPI
10 mc12	75%	1	41%	14	f	VPI
11 af11	70%	1	42%	23	m	VPI
12 em23	70%	1	54%	23	f	VPI
13 rm48	70%	1	53%	5	m	VPI
MEAN	81%		38%	19		
SD	10%		15%	8		

DATA FROM ALL SAMPLES RATED WITH 85% OR MORE LISTENERS' AGREEMENT DURING WORD PRODUCTION

	SUBJECTS	AGREEMENT	NASALITY	NASALANCE	AGE	SEX	CONDITION
1	af42	100%	0	11%	24	f	control
2	vm56	100%	0	30%	28	f	control
3	co66	95%	0	33%	21	f	control
4	fb62	90%	0	38%	10	m	VPI
5	rn60	90%	0	15%	14	m	control
6	jd65	85%	0	11%	22	f	control
1	lb67	90%	1	41%	21	f	control
2	js44	90%	1	58%	12	m	VPI
3	lm21	85%	1	46%	24	f	VPI
4	vs27	85%	1	57%	10	m	VPI
	MEAN	91%		34%	19		
	SD	6%		17%	7		

DATA FROM ALL SAMPLES RATED WITH LESS THAN 70% LISTENERS' AGREEMENT DURING WORD PRODUCTION

	SUBJECTS	AGREEMENT	NASALITY	NASALANCE	AGE	SEX	CONDITION
1	mb50	65%	0	50%	20	f	VPI
2	ll51	60%	0	49%	4	f	VPI
3	ee24	55%	0	19%	42	m	control
4	ds54	50%	0	37%	24	f	VPI
5	mt53	50%	0	39%	21	f	control
6	cm40	50%	0	36%	22	f	control
7	mb14	65%	1	48%	25	f	VPI
8	tm08	65%	1	71%	54	f	VPI
9	tt22	65%	1	46%	8	f	VPI
10	da64	60%	1	56%	8	m	VPI
11	iv20	60%	1	50%	15	m	VPI
12	as39	60%	1	66%	21	f	VPI
13	pl32	60%	1	43%	25	m	VPI
	MEAN	59%		47%	22		
	SD	6%		13%	14		

DATA FROM ALL SUBJECTS WITH SUSPECTED VPI
DURING PHRASE PRODUCTION

	SUBJECTS	AGREEMENT	NASALITY	NASALANCE	AGE	SEX	CONDITION
1	js44	75%	1	60%	12	m	VPI
2	da64	80%	1	48%	8	m	VPI
3	iv20	70%	1	38%	15	m	VPI
4	fb62	100%	0	39%	10	m	VPI
5	mb14	85%	1	49%	25	f	VPI
6	ra10	90%	1	53%	17	f	VPI
7	hs55	75%	0	29%	18	m	VPI
8	ds54	80%	1	36%	24	f	VPI
9	dr49	70%	1	54%	13	f	VPI
10	rd45	80%	0	26%	22	m	VPI
11	fr15	100%	1	52%	35	f	VPI
12	as39	90%	1	65%	21	f	VPI
13	mc12	80%	1	38%	14	f	VPI
14	ab35	75%	0	55%	33	m	VPI
15	tt22	80%	1	34%	8	f	VPI
16	lm21	80%	1	50%	24	f	VPI
17	ll51	55%	1	53%	4	f	VPI
18	rm48	55%	1	46%	5	m	VPI
19	af11	65%	1	36%	23	m	VPI
20	tm08	55%	1	74%	54	f	VPI
21	em23	65%	1	45%	36	f	VPI
22	mb50	65%	0	51%	20	f	VPI
23	sm45	50%	0	59%	7	m	VPI
24	pl32	50%	0	42%	25	m	VPI
25	cm26	65%	0	25%	25	f	VPI
26	vs27	85%	1	44%	10	m	VPI
27	wa36	75%	0	30%	4	m	VPI
	MEAN	74%		46%	19		
	SD	14%		12%	12		

DATA FROM ALL SAMPLES WITH NORMAL PERCEPTUAL RATINGS DURING PHRASE PRODUCTION

	SUBJECTS	AGREEMENT	NASALITY	NASALANCE	AGE	SEX	CONDITION
1	jd65	90%	0	14%	22	f	control
2	fb62	100%	0	39%	10	m	VPI
3	rn60	75%	0	8%	14	m	control
4	vm56	100%	0	22%	28	f	control
5	hs55	75%	0	29%	18	m	VPI
6	jd47	70%	0	22%	22	f	control
7	sp46	75%	0	19%	32	f	control
8	rd45	80%	0	26%	22	m	VPI
9	af42	95%	0	9%	24	f	control
10	ab35	75%	0	55%	33	m	VPI
11	jd31	85%	0	12%	21	f	control
12	lb67	65%	0	30%	21	f	control
13	co66	65%	0	24%	21	f	control
14	mt53	60%	0	22%	21	f	control
15	al52	50%	0	42%	26	f	control
16	mb50	65%	0	51%	20	f	VPI
17	sm45	50%	0	59%	7	m	VPI
18	pl32	50%	0	42%	25	m	VPI
19	ee24	65%	0	14%	42	m	control
20	cm26	65%	0	25%	25	f	VPI
21	wa36	75%	0	30%	4	m	VPI
	MEAN	73%		28%	22		
	SD	15%		14%	8		

DATA FROM ALL SAMPLES WITH HYPERNASAL PERCEPTUAL RATINGS DURING PHRASE PRODUCTION

	SUBJECTS	AGREEMENT	NASALITY	NASALANCE	AGE	SEX	CONDITION
1	js44	75%	1	60%	12	m	VPI
2	da64	80%	1	48%	8	m	VPI
3	iv20	70%	1	38%	15	m	VPI
4	mb14	85%	1	49%	25	f	VPI
5	ra10	90%	1	53%	17	f	VPI
6	ds54	80%	1	36%	24	f	VPI
7	dr49	70%	1	54%	13	f	VPI
8	fr15	100%	1	52%	35	f	VPI
9	as39	90%	1	65%	21	f	VPI
10	mc12	80%	1	38%	14	f	VPI
11	tt22	80%	1	34%	8	f	VPI
12	lm21	80%	1	50%	24	f	VPI
13	ll51	55%	1	53%	4	f	VPI
14	rm48	55%	1	46%	5	m	VPI
15	cm40	65%	1	32%	22	f	control
16	af11	65%	1	36%	23	m	VPI
17	tm08	55%	1	74%	54	f	VPI
18	em23	65%	1	45%	36	f	VPI
19	vs27	85%	1	44%	10	m	VPI
	MEAN	75%		48%	19		
	SD	12%		11%	12		

DATA FROM ALL SAMPLES RATED WITH 70% OR MORE LISTENERS' AGREEMENT DURING PHRASE PRODUCTION

	SUBJECTS	AGREEMENT	NASALITY	NASALANCE	AGE	SEX	CONDITION
1	js44	75%	1	60%	12	m	VPI
2	da64	80%	1	48%	8	m	VPI
3	iv20	70%	1	38%	15	m	VPI
4	mb14	85%	1	49%	25	f	VPI
5	ra10	90%	1	53%	17	f	VPI
6	ds54	80%	1	36%	24	f	VPI
7	dr49	70%	1	54%	13	f	VPI
8	fr15	100%	1	52%	35	f	VPI
9	as39	90%	1	65%	21	f	VPI
10	mc12	80%	1	38%	14	f	VPI
11	tt22	80%	1	34%	8	f	VPI
12	lm21	80%	1	50%	24	f	VPI
13	vs27	85%	1	44%	10	m	VPI
14	jd65	90%	0	14%	22	f	control
15	fb62	100%	0	39%	10	m	VPI
16	rn60	75%	0	8%	14	m	control
17	vm56	100%	0	22%	28	f	control
18	hs55	75%	0	29%	18	m	VPI
19	jd47	70%	0	22%	22	f	control
20	sp46	75%	0	19%	32	f	control
21	rd45	80%	0	26%	22	m	VPI
22	af42	95%	0	9%	24	f	control
23	ab35	75%	0	55%	33	m	VPI
24	jd31	85%	0	12%	21	f	control
25	wa36	75%	0	30%	4	m	VPI
	MEAN	82%		36%	19		
	SD	9%		16%	8%		

DATA FROM ALL SAMPLES RATED WITH 85% OR MORE LISTENERS' AGREEMENT DURING PHRASE PRODUCTION

	SUBJECTS	AGREEMENT	NASALITY	NASALANCE	AGE	SEX	CONDITION
1	mb14	85%	1	49%	25	f	VPI
2	ra10	90%	1	53%	17	f	VPI
3	fr15	100%	1	52%	35	f	VPI
4	as39	90%	1	65%	21	f	VPI
5	vs27	85%	1	44%	10	m	VPI
6	jd65	90%	0	14%	22	f	control
7	fb62	100%	0	39%	10	m	VPI
8	vm56	100%	0	22%	28	f	control
9	af42	95%	0	9%	24	f	control
10	jd31	85%	0	12%	21	f	control
	MEAN	92%		36%	21		
	SD	6%		19%	8%		

DATA FROM ALL SAMPLES RATED WITH LESS THAN 70% LISTENERS' AGREEMENT DURING PHRASE PRODUCTION

	SUBJECTS	AGREEMENT	NASALITY	NASALANCE	AGE	SEX	CONDITION
1	ll51	55%	1	53%	4	f	VPI
2	rm48	55%	1	46%	5	m	VPI
3	cm40	65%	1	32%	22	f	control
4	af11	65%	1	36%	23	m	VPI
5	tm08	55%	1	74%	54	f	VPI
6	em23	65%	1	45%	36	f	VPI
7	lb67	65%	0	30%	21	f	control
8	co66	65%	0	24%	21	f	control
9	mt53	60%	0	22%	21	f	control
10	al52	50%	0	42%	26	f	control
11	mb50	65%	0	51%	20	f	VPI
12	sm45	50%	0	59%	7	m	VPI
13	pl32	50%	0	42%	25	m	VPI
14	ee24	65%	0	14%	42	m	control
15	cm26	65%	0	25%	25	f	VPI
	MEAN	60%		40%	23		
	SD	6%		15%	13		

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I certify that I have read this study and that in my opinion it conforms to acceptable standards of scholarly presentation and is fully adequate, in scope and quality, as a dissertation for the degree of Doctor of Philosophy.

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